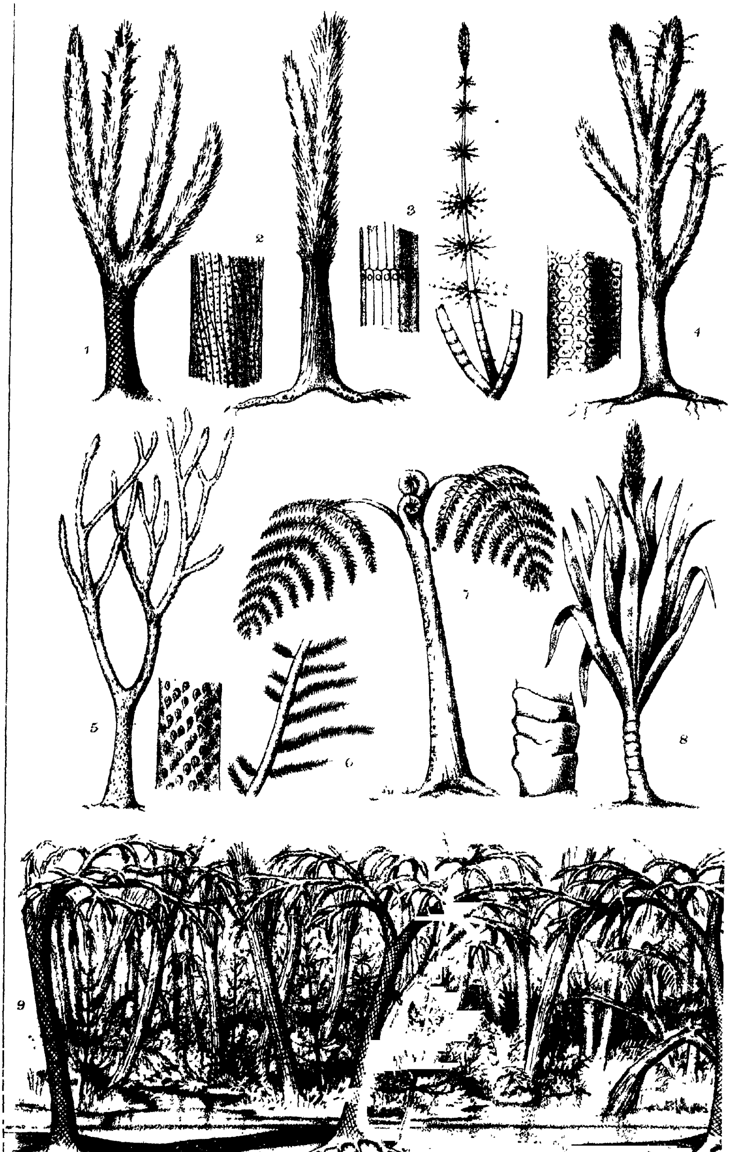
THE COAL-FIELDS OF GREAT BRITAIN.

Frontispiece



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Plants of the Coal Period

THE

COAL-FIELDS OF GREAT BRITAIN:

THEIR

History, Structure, and Resources.

WITH

DESCRIPTIONS OF THE COAL-FIELDS OF OUR INDIAN AND COLONIAL EMPIRE, AND OF OTHER PARTS OF THE WORLD.

BY

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With Maps and Illustrations.

FOURTH EDITION, REVISED.

EMBODYING THE REPORTS OF THE ROYAL COAL-COMMISSION.

LONDON:
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TO

The Memory of

SIR RODERICK I. MURCHISON, BART., D.C.L., F.R.S.,

LATE DIRECTOR-GENERAL OF THE GEOLOGICAL SURVEY

OF THE UNITED KINGDOM.

PREFACE TO THE FOURTH EDITION.

This Edition has been largely re-written. It contains an entirely new chapter on Carboniferous Plants, kindly drawn up by Professor Williamson, F.R.S., of Manchester. The classification of the Carboniferous Series of Beds has been modified in accordance with the views enunciated in my paper on this subject read before the Geological Society of London in 1877, and published in the Journal of that Society.* The account of the various Coal-fields has been modified in accordance with more recent investigations as far as my information extends, and the statistical portions have been brought down to the date of 1878, the returns issued by the Mining Record Office for 1879 not having reached me in time for publication

* Quart. Journ. Geol. Soc., No. 132, p. 613.) (1877.)

further than the total output of coal for each division of the three kingdoms.

My acknowledgments are due, and are hereby tendered, to Dr. S. V. Hayden, Superintendent of the U. S. Geological Surveys; to Professor Williamson, F.R.S.; Mr. De Rance, F.G.S., of the Geological Survey; Mr. G. A. Lebour, F.G.S.; Mr. R. Hunt, F.R.S., of the Mining Record Office, and his assistant Mr. R. Meade, and to several other gentlemen whose services are noted in place, including the Right Hon. Sir M. Hicks-Beach, M.P., who, when in office as Colonial Secretary, furnished me with returns of the output of coal from various colonial districts.

E. H.

DUBLIN, *December*, 1880.

PREFACE TO THE THIRD EDITION.

So many years have elapsed since the publication of the first edition of this work, and so great has been the advance in our knowledge of the Coal-fields of nearly all countries within this period, that, in order to make the reader acquainted with it, I have found it necessary to re-write the greater portion of the book.

Within the interval here alluded to, the following are some of the more important events which have occurred in reference to the subjects herein treated :—

1. A great step towards completion has been made in the Government surveys of the British coal-fields.
2. In British India, the Government surveys of the important coal-fields lying along

the valley of the rivers Damuda and Nerbudda have been completed, and the results published.

3. An important addition to our knowledge of the coal-fields of the European continent has been made, by the publication of the joint work of Professors Geinitz, Fleck, and Dr. Hartig, entitled "Die Steinkohlen Deutschlands und Anderer Länder," in three elaborate volumes, containing descriptions illustrated by maps and drawings of the coal-fields of Europe, together with their palæontology, and the technical and mechanical operations connected with coal-mining; to this may also be added the publication of Dr. Hochstetter's "New Zealand," in which the coal-fields of that wonderful island are very fully described.

The fourth and last event I would here record, is the publication of the Report of the Royal Commissioners appointed by Her Majesty to enquire into the coal-resources of Great Britain, and

matters connected with the consumption of coal. In the following pages I have endeavoured to embody the results arrived at by the Commissioners with the subject matter of the work, so as to bring them within reach of the general public.

The addition to this work of the maps of individual coal-fields, together with its growth in size, owing to the number and variety of details, renders an increase of cost unavoidable, for which I trust the reader will consider he gets full value.

From amongst the numerous expressions of approval which this work has received, both from public men and from reviewers, the author is contented to select one, extracted from the speech of the Earl of Derby (then Lord Stanley), delivered before the British Association for the Advancement of Science, at Birmingham, in 1865. Speaking on "The Coal-question," his Lordship says, "For those who desire to go more deeply into the facts of the case, as far as they are known, than is possible within the limits of an oral address, I should recommend

two books on the subject, published within the last two or three years,—one by Mr. Hull, the other by Mr. Jevons. They differ somewhat widely in conclusions. The one takes what we may call 'the sanguine view' of the case, the other a view comparatively despondent; but in both one and the other you will find what is, perhaps, more important than the inferences of those authors, and that is, a very ample stock of materials upon which to found your own conclusions."—*Daily News*, 11th Sept., 1865.

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INTRODUCTORY.

Owing to the want of reliable information regarding the resources of the British coal-fields, as exhibited during the debates in Parliament on the Commercial Treaty with France in 1860, I ventured, in the following year, to bring out the first edition of this work, in which I gave estimates of the quantity of coal, both in the known coal-fields, and also beyond their visible limits down to a depth of 4,000 feet from the surface. For this undertaking I had at command both the results obtained by the Government Geological Surveyors, as also much information voluntarily tendered by friends who had personal knowledge of various coal-fields, some of which had not at that time been examined by the Government Surveyors.

In 1866, the question of the duration of our coal-supplies, and other matters dependent thereon, were entrusted for examination to a

Royal Commission, consisting of gentlemen of the highest position and experience, who in 1871 issued an elaborate Report, dealing with the question of the actual quantities of coal in the visible and concealed coal-fields of the British Isles; and also with other cognate subjects, such as the probable increased rate of production, loss and waste in working, and the possible exhaustion of our underground supplies. Professor Jevons also, in his work entitled "The Coal Question," ably followed up similar inquiries founded avowedly upon the data furnished in an early edition of this work. Hence these important subjects, which are so intimately connected with the commercial prosperity of this kingdom, have now received very full investigation; and, I may venture to say, will at all times continue to furnish matter for discussion on the part of statesmen and political economists.

The first evidence of a decreasing supply of coal throughout the country will be a sensible rise in price; but through the agency of railways this will not become general until the resources of all the coal-fields shall have been fully developed; because, when the supply shortens in one district, a corresponding impetus will be

given to mining enterprise in another, as long as the coal-seams remain unexhausted. This reciprocal process has possibly already come into operation; in illustration of which the following case may be mentioned. Many of us may live to see the southern half of the South Staffordshire coal-field exhausted, or nearly so; but while this consummation is approaching, the northern half of the same great coal tract is far from being developed to the extent of which it is capable. The exhaustion of the southern portion is already telling upon the northern.

In speaking of the exhaustion of a coal-field, I do not use the term in an absolute sense. There will always be bands of coal, besides leavings in the coal mines, sufficient to afford a small supply to the immediate neighbourhood for domestic purposes. A coal-field may be said to be exhausted, when it is necessary to import largely from neighbouring districts for manufacturing and more general purposes. From various causes, large quantities of coal have been left in old workings, much of which it will be impossible ever to recover.

I have already said, that the British coal-fields can never be utterly exhausted. This is strictly

true. Even disregarding the coal-beds which lie concealed beneath formations newer than those of the Carboniferous period, there are, in some districts, coal-seams which are buried 6,000, 8,000, and perhaps 12,000 feet beneath the surface, and which, it may be presumed, can never be reached. I refer particularly to the great coal-basin of South Wales, which, as Mr. Vivian has shown, is capable of supplying the whole of England with coal; though for a period far shorter, I believe, than Mr. Vivian estimates. In a future page I shall enter in greater detail into this subject; and here content myself with stating the broad fact of the enormous depth of some of the coal-beds in that basin.* Now, without assigning in this place any theoretical limit to the depth at which coal may be ultimately worked, few will be disposed to deny that coal seams at the depths above stated might as well be buried beneath the waters of the Atlantic, for all the probability there is of their being rendered available.

There are other districts, principally in the Midland counties, where the coal-strata, though

* On the authority of the late Sir H. T. de la Beche and Sir W. Logan, through whose energy the magnificent geological survey of this district is now in the hands of the public.

not in themselves of any very great thickness, dip under higher formations till they reach vast depths. For instance, there is no reason to doubt that coal underlies a portion of the plain of Cheshire, between the coal-fields of Lancashire on the north, Staffordshire on the east, and Flintshire on the west; yet, in order to reach the highest workable coal-seam under Northwich, it would be necessary to carry the shaft which reaches the great bed of rock-salt at least 4,000 feet deeper than at present.*

There are, however, very large districts in Staffordshire, Leicestershire, and Warwickshire, overspread by strata belonging to the Permian and Triassic formations, where coal may be reached at depths within 3,000 or 4,000 feet. In the north-eastern counties of Durham, Yorkshire, and Notts, there are also vast stores of fossil-fuel within reach, but overspread by formations belonging to similar geological periods. In Durham, the Magnesian Limestone, which attains there a thickness of 500 feet, has for several years been penetrated in various places down to

* It has been estimated that there are in England and Wales no less than 48,465 millions of tons of coal at a greater depth than 4,000 feet, and reaching down to 10,000 feet from the surface, where the temperature would be 3° higher than that of boiling water.—"Report of Coal-Commission," vol. i., p. 17.

the underlying coal; and the same formation, in its southerly extension into Yorkshire and Nottinghamshire, bids fair to give rise to a coal-producing district of large extent and capacity.*

The depth of many coal-shafts in the north of England is already very great. The "Arley mine" is now worked at Rose Bridge colliery, near Wigan, at a depth of 815 yards (2,445 feet).† The "cannel" seam is reached by shafts 600 yards in depth, in at least two collieries; Pendleton colliery, near Manchester, is 536 yards deep; Duckinfield, in Cheshire, 686 yards. The Monkwearmouth pit, near Sunderland, has a depth of 530 yards: and collieries with shafts between 400 and 500 yards are not uncommon in the coal-fields of Lancashire, Yorkshire, and Durham.‡ In the Aberdare and Merthyr districts of South Wales are several deep shafts, those of Harris' Navigation Colliery being 760 and 700 yards in depth, to the "upper Four-foot seam."

Notwithstanding, however, all that art and

* See Map.

† Appendix A.; see Brit. Assoc. Rep., 1870, p. 30.

‡ Some of the collieries in Belgium are of great depth; one of these, I am assured, reaches 932 yards or 860 metres, and some in Saxony reach 800 yards and upwards.

industry can invent to facilitate mining at great depths,—notwithstanding the increased powers of machinery and improvements in ventilation, the employment of flat wire ropes, the substitution of steel for wrought iron, and the use of two or more "lifts," or stages, at intervals from the bottom of the mine, we must ultimately reach a depth at which the temperature will be so high as to prohibit inexorably mining operations. What that depth may be I shall discuss in a future chapter: in the meanwhile, let us review briefly the progressive course of coal-mining from its infancy to the present time.

PART I.

CHAPTER I.

FRAGMENTS IN THE HISTORY OF COAL-MINING.

THE first attempts at coal-mining are enveloped in obscurity; but even from the chronicles of those days, when nothing was thought worth recording save the accession of a prince, the feuds of neighbouring states, and the details of a battle, enough has been incidentally noted to enable us to trace back the art of coal-mining to very early times.

Its beginning was sufficiently humble. The nature and property of coal being little understood, there was nothing in the outcropping of a black substance along the sides of a hill or the banks of a brook to arrest attention; but it is not improbable that from the earliest periods—at any rate from the time in which implements and weapons of metal replaced those of flint—

fossil fuel may have been employed for smelting purposes. Fortunately on this point we are not left altogether to conjecture, as I shall have occasion to show presently.

Like many other treasures of Nature, the use of coal did not become general until its necessity had become paramount. While in the days of Anglo-Saxon and Anglo-Norman art, and those which immediately succeeded, the plains of England were overspread with almost continuous forests, growing, as in Staffordshire and Lancashire, frequently in dense luxuriance over the mineralized forests of geologic ages, and while these forests readily yielded an abundance of fuel for all the purposes of the times, it was both unnecessary and improbable that the labour and risk of mining should become general. The precious mineral was reserved for a generation to whose very existence it is almost a necessity; a generation that, without its aid, could scarcely (as far as we can see) have arrived at the position in art, industry, and navigation, which it has attained in the nineteenth century.

I must now ask my reader to accompany me through a few of those details in the history of coal-mining which I have been able to collect. I do not profess to have exhausted the subject;

for the more I have entered into it, the more am I satisfied that much remains to reward the industry of the antiquarian. The notices we find are like stepping-stones for crossing a river; sometimes they are large and closely placed, at other times wide apart, so that we have to make a leap perhaps over several centuries at a time; but I have no doubt further researches will enable us to add to the number of the stone steps, so as to lessen the gaps, if we cannot hope to make a continuous road from the shore of the past to that on which we stand.

It is scarcely necessary to observe, that the frequent references to coal in the Bible cannot be considered as pointing to that mineral as at present understood. The original word doubtless means charcoal, which, like the Latin term, may be employed to designate fuel of both kinds.

Period before Christ.—Theophrastus, a Greek author who lived about 238 years before the Christian era, describes, in brief but determinate language, the nature, uses, and source of coal. It is a sufficient proof of this mineral being intended, that the description applies accurately to it, and to no other. He says: "They call those fossil substances (λιθύς ἄνθρακας) anthracite

(or coal), and when they are broken up for use, are of an earthy character (γεώδεις); nevertheless, they inflame and burn even like charcoal (καθάπερ οἱ ἄνθρακης), and are used by the smiths." He adds, that the coal is found along with amber and other substances in Liguria, and in Elis on the road to Olympias over the mountains.*

There are several other passages in the same work descriptive of combustible minerals, but in such vague language that it is impossible to identify them with certainty. The passage above quoted is, it appears to me, sufficient; and its value would scarcely be strengthened by the addition of a score of others which might be applied to as many different substances.†

Ancient Britons.—It might scarcely be credited, were it not established on incontestable evidence, that there were coal mines amongst those savage clans and roving barbarians, such as we are generally taught to consider the Britons of pre-historic times. The discovery in an old mine of a flint-axe stuck into a bed of

* It is scarcely necessary to give the original passage of which the above is a literal translation, and varies only slightly from that of Mr. John Hill, who edited an edition of the "History of Stones" in 1746. Pennant also notices the passage, and does not hesitate to refer it to coal.

† See also the same author in "Περι Λιθων." Art. 49.

coal in Monmouthshire is a fact which, like the occurrence of a solitary fragment of a plant in a very ancient rock, proves a great deal more than appears at first sight. If we accept the theory, that flint weapons were the earliest representation of three stages of civilization, ot which bronze implements were the second, and iron implements the third, this discovery carries us back to a very early period, antecedent to the invasion of the Romans.

Sir C. Lyell informs us, on the authority of the late Mr. Smith of Jordan Hill, that a rude ornament, made of cannel coal, was found on the coast in the parish of Dundonald, lying fifty feet above the sea-level, on a surface of boulder clay, and covered with gravel containing marine shells. The writer adds: "If we suppose the upward movement to have been uniform in central Scotland before, and after, the Roman era, and assume that twenty-five feet indicate seventeen centuries, we should then carry back the date of the ornament in question to fifteen centuries before our era, or to the days of Pharaoh, and to the period usually assigned to the exodus of the Israelites from Egypt.*

Coming down to less ancient times, I may

* "Antiquity of Man," p. 55.

mention the following case. Near Stanley, in Derbyshire, some years since, while some miners were engaged in driving a heading through the "Kilburn coal," they broke into some very old excavations, in which they found axes or picks formed out of solid oak. The implements were entirely destitute of metal, and were cut out from one solid piece of timber. It is hard to imagine the use of such instruments where iron was known; while it is also difficult to conjecture how an axe of this kind could have been formed without the assistance of iron. The neighbourhood of these old workings abounds in iron-ore, several beds of clay iron-stone occurring both above and below the Kilburn coal. If the use of these ores had been known, it is scarcely to be supposed that the miners would have made use of picks formed entirely of oak. Implements which appear to have belonged to an equally early period are stated to have been found in old coal-workings near Ashby-de-la-Zouch, consisting of stone hammer-heads, wedges of flint, as also wheels of solid wood.*

Whittaker states that there is indubitable evidence from the discoveries at Castle-Field, near

* Mammat's "Geological Facts."

Manchester, that the Britons had made use of coal in that neighbourhood. He refers to the existence of fragments of coal in the beds of sand *under* the Roman road, and in a pit a few feet deep contiguous thereto. But I very much doubt the value of such evidence. Those acquainted with the Drift, or Post-pliocene, deposits of Lancashire and Cheshire, know that drifted fragments of coal are extremely plentiful therein; and there is strong probability that those upon which he dilates so enthusiastically were carried to their beds in the sand long even before the time of the *Aborigines* of Britain; and, therefore, not by the hand of man.

Romans in Britain.—That the Romans were acquainted with the use of coal during their occupation of Britain is highly probable, both from what we know of the character of the race and from circumstantial evidence. They had stations in many places close to the out-crop of valuable coal-seams, and cinders have been found amongst the ruins of Roman towns and villas.

If Whittaker, the historian of Manchester, has been unsuccessful, as it appears to me at least, in establishing upon satisfactory evidence the use of coal by the Ancient Britons, he has been more fortunate in showing that fossil fuel from the

Lancashire coal-field was burnt by their successors, the Romans. Castle-Field—an original settlement of the Britons—was afterwards possessed by the Romans under the name of "Mancunium." In the course of time it has slightly changed its name, and developed into the metropolis of the northern counties of England. Whittaker states, that amongst other Roman remains turned up about a century ago, cinders and scoriæ were discovered in several places, as well as the "actual refuse of some considerable coal-fire."*

The same author also relates, that in the West Riding of Yorkshire, near North Brierley, a quantity of Roman coins, the very best indices for dates, were found "carefully reposited" amid many beds of coal-cinders heaped up in the adjacent fields.†

Horseley, speaking of some inscriptions found at Benwell, near Newcastle-upon-Tyne, the Condercum of the Romans, states that there was "a coalry not far from that place, which is judged by those best skilled in such affairs to have been wrought by the Romans."‡ Wallis also states,

* "History of Manchester," vol. i., p. 301.

† *Ibid.*, vol. i., p. 303.

‡ "Britannia Romana."

that in digging some of the foundations of the city of Magna, or Caervorran, in Northumberland, in 1762, cinders, in all respects similar to those derived from coal, were found in considerable quantity.*

Mr. T. J. Taylor, in an article on the "Archæology of the Coal-trade,"† also refers to the discovery of coal-cinders as part of the relics of the Roman stations of the neighbourhood of Newcastle-upon-Tyne, notices of which are contained in the records of the Antiquarian Society of that town.

Similar evidences of the use of coal by the Romans are stated to have been discovered at Lanchester, and Elchester, in the county of Durham.

One of our most laborious investigators in the field of archæology, Mr. T. Wright, considers that the Shropshire coal-field was "discovered" by the Romans. Not far from the borders of this coal-field stood the ancient Uriconium, now the village of Wroxeter; and during the recent explorations, which resulted in bringing to light many objects of interest in the domestic arrangements of the Roman inhabitants, considerable quanti-

* "Hist. of Northumberland."

† Proc. Archæol. Institute of Newcastle, vol. i., p. 151.

ties of coal—both in the raw state and partially consumed—were found, having been used apparently in heating the ovens. The fragments appeared to be of inferior quality, such as occurs when they are extracted at no great depth from the out-crop of the seams.* It is scarcely necessary to remind the reader that metallic mining was very largely carried on by the Roman colonists along the border counties of Flintshire, Denbighshire, and Shropshire, many of the principal lead mines having been opened up by them.

Assuming, from the general consideration of the case, that coal was not unknown to the Romans—though they do not appear to have invented a name for it while in Britain, and it was probably used more from curiosity than from necessity—we enter upon the Anglo-Saxon period, in which there is documentary evidence of the use of pit-coal for domestic purposes.

Anglo-Saxon Period.—Britton, in his description of Peterborough Cathedral, renders into modern English the following paragraph taken from the Saxon Chronicle of the Abbey of Peterborough:—"About this time (A.D. 852) the Abbot Ceolred let to hand the land of Sempring-

* "Intellectual Observer," No. 4.

ham to Wulfred, who was to send each year to the monastery '60 loads of wood, 12 loads of coal, 6 loads of peat, 2 tuns full of fine ale, 2 neats' carcases, 600 loaves, and 10 kilderkins of Welsh ale, 1 horse also each year, and 30 shillings, and one night's entertainment.'"* How Wulfred was to send the provident abbot "one night's entertainment" it is not necessary for our purpose to inquire; but this statement of the chronicler is highly valuable as establishing the fact that coal was at this early period an article of household consumption. It may also have been made use of by the monks, who were the artificers and craftsmen of their times, in the manufacture of metal-work for the churches and monasteries.

In connection with this period, it is matter for discussion whether our term "coal," which is evidently identical with the German "kohle," has been derived from our Saxon ancestors, or whether, on the other hand, the Germans have derived it from us. It is probable the term was in general use before the invasion of the Normans, otherwise the French (or Latin) name would in all probability have been adopted. The Saxon name *col* (German *kohle*) appears to have superseded the old British name *glo*, and if intro-

* "Cathedral Antiquities," vol. v.

duced into Britain at the colonization of the country by the German tribes, it is in favour of the supposition, that the art of coal-mining was practised in Europe during the first centuries of the Christian era.*

* I have been favoured with the following note on the derivation of the word Coal, by my relative, the late Mr. William J. Leacock, which I give entire :—

"There are only five copies extant of the original Saxon Chronicle, of which four are in the British Museum. The original Anglo-Saxon words used in reference to Wulfred's rent to the Abbot of Peterborough are—'anꝺ ꞇpælꝼ ꝼoðuꞃ ᵹꞃæꝼan,' *i.e.*, in modern English letters, 'and twælf rothur græfan.' Bosworth, in his A.S. Dictionary, gives under Græfe, an; m. Coal: Carbo fossilis, Chr. 852 (*i.e.*, the above passage), so that this seems to be the only passage in which the term is used. No derivation is given, and I can find no parallel in the Dutch or German; but perhaps, as we have Anglo-Saxon 'Greaf or Graf,' Dutch the same, German 'Grab,' and so through all the northern languages, for a trench or 'grave,' it simply means the 'dug-up' earth.

"I find, however, in the A.S. Dictionary, 'Col. plur. cola, colu. [Ters., *i.e.*, Teiresia *hôal*, Dutch hool.] Coal, carbo: with reference to Psalm xviii. 12, 13, and cxxxix. 11, *i.e.*, the Psalms by Spelman, London, 1640, the division of the Vulgate being used.' (Psalm cxl. 10, Eng. Ver.)

"There is also Gled, Gloed, plur., with many parallels in the northern languages, meaning a burning coal, coal, fire; carbo, used in Psalm xviii. 12, etc.

"In Somers' A.S. Dictionary, the word *Græfa* is not to be found; but *Græf*, which means a grove as well as a grave. He gives 'Col. carbo., a coal to burn;' but says nothing about derivation.

"The following is Richardson's etymological account of the

If we have derived the term "coal" from our Saxon forefathers, from whom did they derive it? On this point my late esteemed and erudite friend, the Rev. W. C. Coleman, a man who combined an unusual amount of linguistic and scientific knowledge with an ardent love of natural history, has favoured me with his views on this interesting topic, in a letter which I gladly avail myself of this opportunity of publishing.*

My correspondent says: "Regarding the derivation of the word COAL, I believe it is to be referable to a pretty widely-spread root, signifying simply *Black*. Sanscrit it is काल, and in Arabic character كالا=kálá. This occurs in Turkish in the form كرا=kárá, with the dialectic change of r for l;—*e.g.*, Kárá-on, the Black water; Kara Denghoz, the Black Sea; Kara Dagh, the Black Mountain. Also in Greek, in the form Κελαινος, used for *Black* by Homer, and which implies the existence at an earlier period of a simpler form, Κελας. No doubt the root occurs in other lan-

word 'Coal.' He says it is 'of unsettled etymology. A.S. *Col:* German and Dutch, *Kohle:* Swedish, *Kol.*' Vossius derives from the Greek, χαλεος pro χηλεος, Ignis epitheton. Wachter from χηλοειν, comburere. Ure seems to decide for the Swedish *Quilla*, Westro-Goth *Kylla*, accendere ignem (to kindle a fire)."

* Dated from Burton-on-Trent, 5th Feb., 1862.

guages, but I have not the means of examination at hand. Perhaps the Arabic قار gâr = asphalte, may also have something to do with it."

Anglo-Norman Period.—It is matter for surprise, as well as regret, that in the great survey of England carried out by William the Conqueror, and recorded in that most matter-of-fact of all books, the Domesday Book, no instructions were delivered to the commissioners for inquiring into the extent and value of the mineral property of the central and northern counties. They appear to have confined their investigations entirely to the extent, rights, and ownership of the surface land, together with the classification of the inhabitants; but throughout the counties of York, Lancashire, Derby, and Nottingham, abounding in coal and other minerals, no mention whatever is made of these latter sources of wealth.

In order to test this point, I turned to the page relating to Chellaston in Derbyshire, where a most valuable bed of gypsum, or alabaster, underlies a large extent of surface at no great depth, and crops out as a solid bed ten or twelve feet in thickness. This mineral (which we know to have been worked centuries ago) could not even at that time have been undiscovered, for the ploughshare scrapes its surface in many

places, and it may well be supposed to have been a source of wealth to the owner. Yet there is no mention made of the mineral value of the property in the "Dom Boc." Even the lead mines of Derbyshire, known to have been worked by the Romans, are unnoticed, and therefore we need not be surprised that coal receives no mention.

However, in the Boldon Book, containing the census of portions of the northern counties, and published in the reign of Henry II., we find at least two references to coal. It is here stated that the carpenter of Vernouth (now Wearmouth) who is an old man, holds twelve acres for life for making carts and harrows for the tenants, and that the smith (Faber) has an equal quantity of land for the iron-work of the carts, and finds the requisite coal (carbonem invenit). I think this passage can scarcely be considered as referring to charcoal obtained from wood. In this sense the verb *invenit* would be inapplicable, but is not so when used in reference to a kind of fuel which requires discovery. The census of Seggefeeld follows very closely upon that of Vernouth, and here also the smith of the village is said to find the coal for his forge.* What a curious insight

* Inquisitio de consuetudinis, et reditibus totius Ep'atus Dunelmensis, Anno 1183. The difficulty of reading this work,

into the customs of those times is afforded by these passages! In the small communities of Vernouth and Seggefeeld, the carpenter and smith are bound to keep in repair, and probably provide, the implements of agriculture for the farmers in consideration of a certain extent of land; money being probably not in general use amongst the villagers of that period.

In 1180, a grant of land was made to a collier (as stated by Bishop Pudsey) for providing coals to a cartsmith of Counden, in the county of Durham; another instance of a similar kind.*

The year 1259 is memorable in the annals of coal-mining. Hitherto the mineral had not been recognized by authority, or in any public document; but in that year King Henry III. granted a charter to the freemen of Newcastle-on-Tyne for liberty to dig coal. Under the term "sea-coal" a considerable export trade was established with London, and it speedily became an article of consumption amongst the various manufacturers of the metropolis. But its popularity

which, like the Domesday Book, is full of abbreviations and elliptical expressions, is great. As examples, I quote the passages above alluded to:—"Vernouth. Faber xii. acr' ꝑ ferramentę caruc' & carbones qm' invenit." "Faber, 1 bovat. ꝑ ferrametę carruc'. que fac'. & carbon' invenit."

* Mr. R. L. Galloway has given an interesting account of the earliest records of Coal-mining on the Tyne in the Proc. Soc. Antiq., Newcastle-upon-Tyne, Ap. 1879.

was short-lived. An impression became general that the smoke arising therefrom contaminated the atmosphere, and was injurious to the public health. Years of experience has proved the fallacy of the imputation; but in 1306 the outcry became so general that the Lords and Commons in Parliament assembled presented a petition to King Edward I., who issued a proclamation forbidding the use of the offending fuel, and authorising the destruction of the furnaces and kilns of all who should persist in using it. This was a year before the monarch's death, and the year which saw the overthrow of his life-long attempts upon the throne of Scotland, through the intrepidity of Robert the Bruce. But the proclamation against coal was as abortive as the endeavour to conquer the patriotism of the Scots. Prejudice gradually gave way as the value of the fossil fuel became better known, and from that time downwards its use became more extended. It is very probable that throughout the 14th and 15th centuries coal was extracted near the outcrop of the beds over most, if not all, of the coalfields of Britain and Ireland. Historical records are still extant from which we learn that collieries were opened during the 14th century in various parts of Yorkshire, Durham, and Northumberland.

The anonymous author of the "History of Fossil Fuel" observes in reference to the 13th

century: "The strongest and most unequivocal proof that this species of fuel (coal) was in use amongst us during the reign of Henry III. is to be found in an inquisition preserved among the additions to Matthew Paris's History, of the date of 1245. Here we find it called *carbo maris*, or *sea-coal*—an appellation retained through succeeding centuries—with express mention of making pits to win it, and of the wages of the colliers that wrought in them."

Leland * has the following passage: "The vaynes of the se-coles ly sometyme upon clines of the se, as round about Coquet Island, and other shores; and they, as some will, be properly called se-coles: but they be not so good as the coles that are digged in the inner part of the lande."

We have numerous references to the use of coal in the 14th century.† Surtees, in his "History of Durham," mentions a coal-mine in connection with the vicarage of Merrington, in the county of Durham, in 1343; and also notices the sinking of pits at Ferryhill, in the same county.

* "Itinerary," vol. viii.

† Coal seems to have been discovered near Newcastle early in the 13th century; according to Rymer's "Fœdera" it was made an article of trade in London in the reign of Richard II. (1381), and generally burnt by the inhabitants of the metropolis in the year 1400.

Mr. Taylor, in the Memoir already alluded to, says: "We have thus a tolerably clear historical account of the Newcastle coal-mining and its adjuncts in the 14th century. We have seen that collieries were then certainly opened over a considerable extent of our coal-field, since they were being worked in the districts of Newcastle, Elswick, Birtley, Winlaton, Merrington, and Lanchester. To these may be added coal-mines in Bedlingtonshire, the produce of which was probably shipped in the river Blyth (Northumberland), for we find the Bishop of Durham in 1368 appointing a supervisor of the mines of that district. That coals were also shipped from Sunderland in the same century we have proof in the rolls of Whitby Abbey in 1395, when '13 shillings and 4 pence were paid to William Rede of Sunderland for four chaldrons of coal.'" *

The use of coal in London was resumed within a few years after its prohibition by the king in 1306; as we find in the "Petitiones in Parliamento," in 1321-2, a claim made for ten shillings on account of coal which had been ordered by the clerk of the palace, but the payment for which had been neglected.

Amongst other incidental notices of coal in the 14th century is that of Æneas Sylvius, afterwards Pius II. On his visit to Scotland he had

* Proc. Archæol. Inst. Newcastle, vol. i.

opportunities of witnessing the poor receiving as alms at the gates of the monasteries pieces of coal, "which," he states, "they burn in place of wood, of which their country is destitute."*

Coal-mines are also mentioned in the abbey leases of this century. Tynemouth priory had a colliery at Elswick in 1330, let at a yearly rental of six marks, to be paid so soon as the tenant commenced working the coal. The rent of another new colliery in 1334 is stipulated at 40*s.* yearly.†

In the reign of Richard II., about the year 1381, coal was made an article of trade in London (Rymer's *Fœdera*). In 1400 it was burnt generally for fuel in the metropolis, and in 1625 throughout the greater part of England.

In the reign of Queen Elizabeth the coal-trade flourished greatly, and continued to be regarded as an important source, not only of local but of national revenue, by succeeding monarchs. In the reign of Charles I. the trade was burdened by excessive taxation and grievous monopolies. After the capture of Newcastle by the Scottish army, the House of Commons undertook the regulation of the coal-trade, by which step supplies were shipped into the port of London for

* "Ænei Sylvii Opera," p. 443. (See Appendix.)

† Proc. Arch. Inst. Newcastle, vol. i.

the use of the poor, coals having previously risen to the price of 4*l.* per chaldron.*

The difficulties under which mining operations were carried on before the invention of the steam engine, and more particularly of the "Davy lamp," must have been very great. An anonymous writer in the "Builder" states, that in many mines the only alternative the mediæval miner had to pitch darkness was the phosphorescent gleam from dried fish.† Those who wish to understand the art of mining as it was carried on at this period will find their curiosity amply gratified by turning over the pages of Agricola's treatise on mining. This author, who wrote in the middle of the 16th century, has illustrated the various processes by a profusion of quaint drawings on a large scale. The horse-gin, which survives to the present day in many districts, was the engine chiefly employed both for lifting the coal, and for getting rid of the water. This latter object was also sometimes effected by means of pumps turned by windmills, or through tunnels driven with great labour to an outlet at a lower level.

Pennant, in his account of the collieries of

* "Hist. Fos. Fuel," p. 316.

† See Appendix E.

Flintshire, states that there is documentary evidence to show that the coal-seams of Mostyn were worked in the time of Edward I.; and in the 17th century, Dublin and the eastern parts of Ireland were supplied from this district.*

In the year 1600, or thereabouts, coal was worked at Bedworth in Warwickshire, as we learn from Camden, who describes the process, and says that the miners assured him that large *toads* had been found in the solid coal.† In this century also the mineral treasures of the bishopric of Durham were well known; and early in the 17th century the cannel-coal of Lancashire was used, not only by the poor for candles, but was manufactured into various articles of ornament or use. Camden, in speaking of the discovery of this rather rare description of coal at Haigh, near Wigan, says: "This neighbourhood abounds with that fine species of coal called *canal* or *candle.* It is curious and valuable, and besides yielding a clear

* "Tour in Wales," vol. i. (1784).

† Camden's "Britannia," Gough's edit., vol. ii., p. 464. This belief amongst miners of the existence of live toads in coal is very extraordinary, and is almost co-extensive with mining itself. I was assured by a miner in Lancashire, near Ormskirk, that a toad had been brought up in a piece of coal from a mine thirty-six yards in depth, which immediately revived on reaching the surface!

flame when burnt, and therefore used by the poor as candles, is wrought into candlesticks, plates, boxes, etc., and takes a fine polish like black marble."*

Dr. Plot, Professor of Chemistry at Oxford, writing in 1686, describes with much minuteness the working of coal and clay-ironstone at Tunstall and Silverdale in North Staffordshire, and also the process by which the reduction of the ore was effected.†

That coal was worked in Ireland at least as early as the beginning of the sixteenth century, and possibly much earlier, may be inferred from the following account given by Hamilton in his "Letters on the Coast of Antrim." He relates that in 1770 the miners of Ballycastle, in pushing forward an adit towards a bed of coal in an unexplored part of the coal-field, unexpectedly broke into a narrow passage, which proved to have been carried several hundred yards to a bed of coal, and then branched off into chambers. Pillars had been left at proper distances, and some remains of tools and baskets were found, which speedily crumbled to pieces. Those who are aware how the accounts of mining operations

* "Britannia," vol. iii., p. 390.

† "Natural History of Staffordshire."

are handed down through several generations, will readily admit that the old works here mentioned, and of which all local tradition had been lost, must have been carried on at least a century and a half before the period when they were afterwards discovered, which would throw back the date nearly to the beginning of the 16th century.

In Scotland the coal-seams of the Lothians and Fifeshire were probably worked at a very early period. The ancient Celtic name still adheres to the little sheet of water, Loch Glow, lying near the border of the Fifeshire coal-field, and along whose banks thin coal-seams crop out. Agricola, and after him Camden, mentions that in his time there existed in the latter county old coal-pits filled with water, and surrounded by mounds of refuse called *coal-heughs;* and he adds that "many of the beds of coal have been on fire for centuries, and the heat still continues to melt the snow on the surface." * These old coal-works would appear to have been at least as old as the 15th century.

In reference to the coal-miners of Scotland, it will probably surprise many persons to learn that

* Camden's "Britannia," vol. iv., p. 114. This elaborate work was published in 1607.

they were held in a state of actual and legal slavery down to the year 1799, when the Act of George III. chap. 56, was passed, by which all colliers in Scotland were declared free from servitude.*

After the great Fire of London, the Lord Mayor was granted an impost of one shilling per chaldron for rebuilding the city, which was further increased to three shillings. An additional tax of two shillings was afterwards imposed by Parliament in 1670, for the purpose of rebuilding fifty-two parish churches; and in 1677 a further tax of three shillings was laid on, partly for rebuilding St. Paul's. The duties for rebuilding the city churches were continued during the reign of Queen Anne. At the period of the great war with France the coal-tax rose to nine shillings and fourpence per chaldron, the whole of which has been repealed, with the exception of the City and Orphans' Duties, amounting to one shilling and a penny per ton.

Campbell, in his "Political Survey of Britain," published in 1774,† gives us some interesting details of the coal-trade in his time. He states, that although coal was employed in

* Lord Cockburn's "Memorials of his Time" (1856).

† Vol. ii., p. 30.

manufactures for several hundred years, it did not come into general use till the reign of Charles I., and was then sold for seventeen shillings a chaldron. In 1670, about 200,000 chaldrons, and at the Revolution (1690) upwards of 300,000, and in the reign of George III. (1760) double that quantity, was annually consumed in Britain. He adds: "There is little room to be alarmed from the apprehension of their (the mines) being exhausted, as the present works are capable of supplying us for a long series of years, and there are many other mines ready to be opened when any of these shall fail,"—a piece of information which must have been exceedingly consolatory to those of the last generation, but not so assuring to us who have lived to see the annual consumption of more than 120 millions of tons.

Sir John Clerk, in a letter to a friend, written in 1739, gives an interesting account of the collieries of Whitehaven.* The coal-beds, even at that time, were worked far under the sea, so that, as the writer observes, Sir James's riches in part swim over his head, for ships pass daily above the very ground where his colliers work. The coals were drawn up by an engine turned

* Belonging to Sir James Lowther.

by two horses, which went their circuits at full trot every eight hours, and three changes were employed every twenty-four hours. Sir John Clerk then proceeds to give a long and minute account of the quantity of coal raised, its cost, and how much the proprietor cleared after paying all expenses, which amounted to the very moderate figure of 600*l.* a year, or thereabout. The writer also states that the upper coal-seams were much exhausted near the sea, but that untouched treasures lay below.

We have now reached the margin of a new epoch in the history of coal-mining, marked by the invention of the steam-engine by Watt in 1784,* and of the safety lamp by Sir Humphrey Davy in 1815. With these inventions a thousand new uses for the application of coal sprung into existence; railways, factories, steam-boats, iron-furnaces were multiplied; and Britain, owing to

* The inventions of Watt extend over a quarter of a century; but the year 1784 was that in which he patented the invention of the parallel motion of the piston-rod, the counter for recording the strokes, the throttle valve, the governor, and the indicator. In that year also he patented a locomotive engine. The "first practical steam-boat" was the "Charlotte Dundas," built by Symington in 1801. The first effective locomotive engine was patented by Trevithick and Vivian in 1802. And at the trial on the Manchester and Liverpool railway, George Stephenson's engine, the "Rocket," gained the prize in 1829.

her enormous riches in coal and iron, taken advantage of by a people endowed with indomitable energy and high intelligence, was enabled to place herself in the front amongst the nations of the old world.

At the commencement of this century, the quantity of coal raised in Great Britain probably did not exceed ten millions of tons. In 1819, according to Mr. R. C. Taylor, the produce of our collieries was thirteen millions. In 1829, or ten years afterwards, 2,018,975 tons were shipped into the port of London alone. In 1840, the total quantity raised in Britain, according to Mr. M'Culloch, was thirty millions. Since then the increase has been rapid, though fluctuating.

In 1850 was passed the Act of Parliament for the appointment of inspectors of coal-mines, a measure loudly called for by the frequent occurrence of appalling accidents. The total loss of life to persons employed in, and about, the collieries of Great Britain during the two years immediately following the passing of the Act, averaged 985 per annum; and the previous mortality was probably greater. Mr. Dickinson, one of H.M. Inspectors for Lancashire, has made a comparison of the mortality amongst the collieries of Belgium and those of this country,

which shows that, as estimated by the number of hands employed, the proportion of deaths in Great Britain to those of Belgium were, in the year 1852, as 5·33 per thousand to 4·05; yet, when estimated by the standard of the quantity of coal raised, the comparison is in favour of this country, having been in the years 1851 and 1852 in the proportion of one life for every 31,000 tons in Belgium, to one life for every 54,822 tons in Britain. The result is owing to the more extensive employment of underground machinery in the coal-mines of this country than in those of the Continent.*

* Memoirs of the Lit. and Phil. Society of Manchester, vol. xii.

CHAPTER II.

ANIMAL REMAINS OF THE COAL-PERIOD.

THE animal life of the coal-period is represented by Reptiles (*Labyrinthodont Amphibia*), Fishes, Insects, Crustaceans, Annelides, and Molluscs.

REPTILES.—The remains of these have been obtained from the South Joggins coal-field of Nova Scotia,* from the Castlecomer coal-field in Ireland,† from the Edinburgh coal-field,‡ from that of Münster-Appel in Rhenish Bavaria,§ and from the coal-field of Saarbrück in Rhenish Prussia.|| Footprints of Labyrinthodont reptiles have also been observed by Professor King, in the Coal-measures of Pennsylvania, and by Mr. Isaac Lea at Pottsville. Reptilian life appears to have been only locally abundant, and entirely absent from many Carboniferous regions. The

* Dawson. Quart. Journ. Geol. Soc., vol. xviii.

† Huxley and Wright. Trans. Roy. Irish Acad., vol. xxiv.

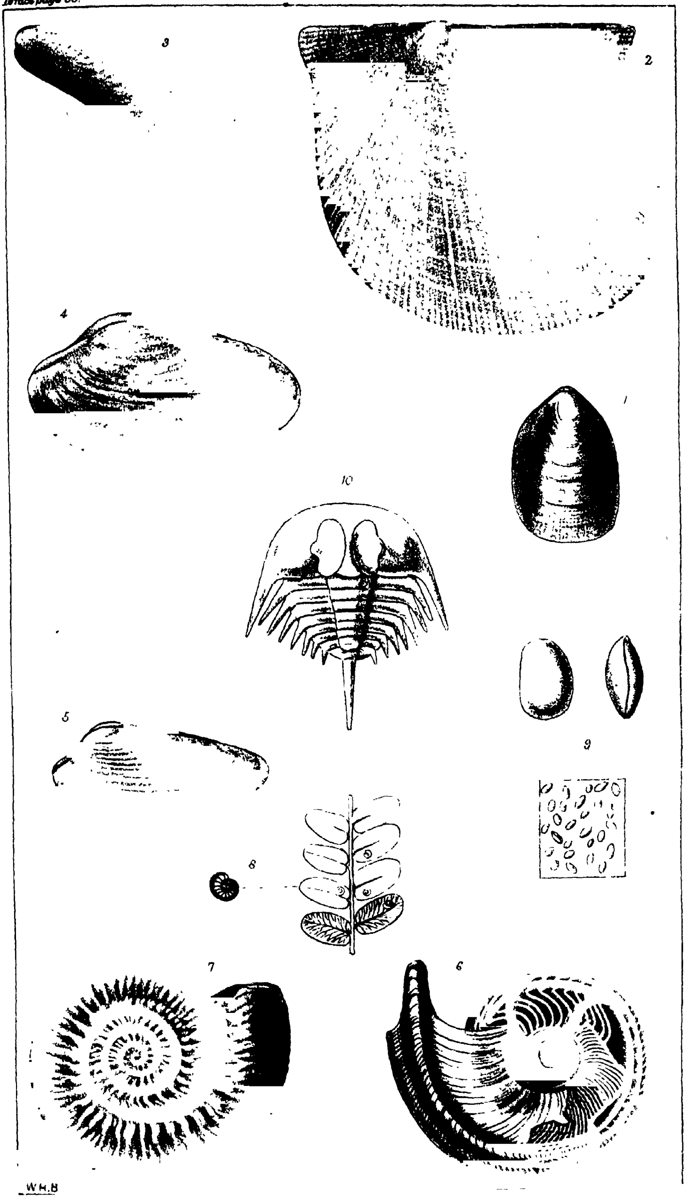
Huxley. Quart. Journ. Geol. Soc., vol. xviii., p. 291, and vol. xix., p. 56.

§ H. von Meyer, quoted by Lyell. "Man. of Geol.," 5th Edit., p. 400.

|| H. von. Dechen, and described by Goldfuss. *Ibid.*, p. 401.

CHARACTERISTIC FOSSILS OF THE COAL FORMATION.

To face page 38.



principal genera are *Anthracosaurus*, *Apateon*, *Archegosaurus*, *Campylopleuron*, *Dendrerpeton*, *Dolichosoma*, *Hylonomus*, *Keraterpeton*, *Loxomma*, *Ophiderpeton* and *Urocordylus*.

FISHES.—The fishes were abundant; their remains, generally confined to teeth or scales, being found in great numbers on the upper surface of the beds of coal, or in the dark shales which in most cases form the roof of the coal-seams. They all belong to the "heterocercal type," and were probably migratory in their habits, frequenting the open sea, as well as the estuaries, lakes, and lagoons of the coal-period. The principal genera are—*Acanthodus*, *Cladodus*, *Cochliodus*, *Cœlacanthus*, *Ctenacanthus*, *Diplodus*, *Gyrolepus*, *Holoptychius*, *Megalichthys*, *Orodus*, *Palæoniscus*, *Platysomus*, *Pœcilodus*, *Psammodus* and *Rhizodus*.

INSECTS, SPIDERS, and MYRIAPODS.—The remains of insects have been found in the Coal-measures of Europe, the British Isles, and America. They include examples of *Blattina*, *Neuroptera*, *Scarabæus*, besides *Arachnida* and *Myriapoda*.* The Coal-measures of Coalbrook Dale, in Shropshire, have afforded several ex-

* The *Arachnida* and *Myriapoda* have been separated from the true insects by Prof. Huxley.

amples,* as well as those of the Saarbrück district, where they are preserved in the nodules of clay-ironstone.* The scarcity of specimens of insects is not to be considered as indicating that insect life was not prolific during the coal-period. On the contrary, considering the perishable nature of the whole animal—except in the case of the elytra of beetles—the wonder is that so many varieties and specimens have as yet been found; and it is very probable that the warm and equable temperature of the coal-period stimulated insect-life to a high extent amongst the moist, shady lagoons and dense forests which overspread such a large portion of the earth's surface.

Crustaceans.—The coal-period appears to have witnessed the extinction of the great family of the trilobites, whose remains are found in such numbers amongst the Silurian Rocks. Specimens of the genus *Phillipsia* have been discovered amongst the shales of the Lower Coal-measures of Kilkenny† and in a similar position in Silesia.‡ Specimens of crustaceans allied to the king crab have been discovered in

* Described by Fr. Goldenberg, Palæont.: Dunker u. H. v. Meyer. Vol. iv.

† Quart. Journ. Geol. Soc., Nov. 1877, p. 621.

‡ F. Roemer, Zeitschr. d. deuts. geolog. Gesellsch, 1863.

the Coal-measures of Coalbrook Dale, and Carlow or Queen's County. The former have been referred by Professor Prestwich to the genus *Limulus*,* the latter to that of *Bellinurus*, of which two species are described by Mr. W. H. Baily.† The marine habitats of these crustaceans is a sufficient reason for their scarcity in the Middle and Upper Coal-measures, which were essentially of fresh-water origin. Entomostraca, however, are very abundant in the shales of the Lower Coal-formation of Scotland and elsewhere.‡

ANNELIDES were represented by *Spirorbis carbonarius*, which is abundant in the shales of the Lower Coal-measures of Britain, and in the limestones of the Upper Coal-measures of Lancashire.§ It is often found adhering to marine shells, as well as to the fronds of ferns and stems of plants, and was probably an inhabitant of estuaries as well as of inland lakes.

MOLLUSCS.—The Molluscs (together with the

* Geol. Trans., 2nd Series., vol. v., p. 440.

† "Explanation" to sheet 137 of the Maps of the Geol. Survey of Ireland, p. 12. A figure of *B. regina* will be found in the Plate of Characteristic Fossils facing the title-page.

‡ See Plate, *ibid.*

§ *Ibid.* The affinities and habits of this annelide are ably discussed by Mr. R. Etheridge, Jun., in the Geol. Mag., May 1880.

Molluscoida) are very fully represented in the Coal-measures of the British Isles, Europe, and America. Many of the species, and all the genera, surviving from the seas of the Carboniferous Limestone period.

The vertical range of these marine forms became a subject of interesting investigation to myself some years ago, and has been discussed in a paper read before the Geological Society of London.* I found that out of thirty-six genera and about seventy species of truly marine forms known to occur in the Lower Coal-measures or "Gannister Beds," only six species pass upwards into the Middle and Upper Coal-measures, which are characterized by bivalve shells of the genera *Anthracosia* and *Anthracomya*, of whose habits we possess but little knowledge. A census of the genera and species, including *Cephalopods*, *Heteropods*, *Gasteropods*, *Conchifera*, and *Brachiopods*, collected from the Lower Coal-measures (or "Gannister Beds") of the British Isles and the West of Europe, shows conclusively that this formation, like those of the Millstone Grit, Yoredale Beds, and Carboniferous Lime-

* "On the upper limit of the essentially marine beds of the Carboniferous group, etc."—Journ. Geol. Soc., Nov. 1877, p. 618.

stone, was essentially of marine origin, and ought to be separated from the Middle and Upper Coal-measures in any future system of classification. To this question I shall have occasion to return, and only now mention the names of the principal genera and species of the Lower, Middle, and Upper Coal-measures.

LOWER COAL-MEASURES ("*Gannister Beds*"). (*Marine.*)

CRUSTACEA.—Phillipsia pustulata (*Schloth.*), Leperditia Okeni (*Nünst.*)

CEPHALOPODA.—Goniatites fasciculatus (*M'Coy*), G. crenistria (*Phil.*), G. Listeri (*Mart.*), G. Gibsoni (*Phil.*), G. Looneyi (*Phil.*), G. reticulatus (*Phil.*) Nautilus armatus (*Sow.*), N. concavus (*Sow.*), N. clitellarius, N. falcatus (*Sow.*), etc., Orthoceras Steinhaueri (*Sow.*), O. scalpratum (*Prestw.*)

PTEROPODA.—Bellerophon apertus (*Sow.*), B. decussatus (*Flem.*), B. hiulcus (*Sow.*), B. navicula (*Sow.*), Conularia quadrisulcata (*Sow.*)

GASTEROPODA.—Euomphalus, Littorina (?), Macrocheilus fusiformis (*Sow.*), Pleuratomaria limbata (*Phil.*)

CONCHIFERA.—Arca, Aviculo-pecten scalaris (*Sow.*), A. gentilis (*Sow.*), A. papyraceus (*Goldf.*), A. alternans (*M'Coy*), A. variabilis (*M'Coy*), Avicula quadrata (*M'Coy*), A. modiolaris, Axinus sulcatus (*Sow.*), Ctenodonta undulata (*Phil.*), Ct. gibbosa (*Flem.*), Ct. æquilis (*Sow.*), Edmondia unioformis (*Phil.*), Myacites sulcatus (*Flem.*), Myalina triangularis (*Sow.*), Pullastra bistriata (*Portl.*), P. scalaris (*M'Coy*), Monotis lævis (*Brown*), Posidonomya Gibsoni (*Brown*), P. lævigata (*Brown*), P. Becheri (*Goldf.*), Schizodus sulcatus (*Sow.*), S. Carbonarius (*Portl.*)

BRACHIOPODA.—Athyris planosculata (*Phil.*), Chonetes Hardrensis (*Phil.*), Discina nitida (*Phil.*), Edmondia, Lingula mytiloides (*Sow.*), Orthis resupinata (*Mart.*), Productus semireticularis (*Mart.*), P. concinnus (*Sow.*), P. scabriculus (*Mart.*), P. hemisphæricus (*Sow.*), Rhynchonella pleurodon (*Phil.*), Spirifera Urii (*Flem.*), S. glabra (*Sow.*), S. bisulcata (*Sow.*), S. pinguis (*Sow.*), S. semireticularis (*Phil.*)

ECHINODERMATA.—Archæocidaris (?), Actinocrinus, Cyathocrinites quinquangularis (*Miller*).

MIDDLE AND UPPER COAL-MEASURES.

(*Estuarine and Lacustrine.*)

The Middle and Upper Coal-measures are characterized by a few forms of bivalves (Conchifera) belonging to the genera *Anthracosia*, (unio), *Anthracomya* and *Anthracoptera*, capable, apparently, of living in fresh water lakes or brackish-water estuaries. At rare intervals, during the deposition of the beds of these stages, the waters of the sea overflowed, bringing with them marine forms, so that we find, as in the cases of the "Bay-coal bass" of Staffordshire, the "Chance-Pennystone" of Coalbrook Dale, and the remarkable bed lying at the top of the Middle Coal-measures of Ashton-under-Lyne,* occasional marine bands amongst vast masses of

* Discovered by Prof. A. H. Green; see "Geology of Oldham," Mem. Geol. Survey.

fresh water strata. With the above exceptions, the Middle and Upper Coal-measures appear to have been deposited under conditions differing from those which prevailed previously, as shown by the general absence of those marine forms which are so prevalent in the subordinate beds.*

Very interesting is the discovery of the shells of air-breathing snails, which have been found in considerable numbers in the trunks of trees, in the South Joggins coal-field, by Dr. Dawson, and more recently in England. *Helix priscus* and *Pupa vetusta* are probably only the representatives of numerous species of the pulminiferous gasteropods of the coal-period.

Tracks of burrowing Annelides, as well as occasionally those of Molluscs and Crustaceans, are common on the surfaces of the flagstones of the Carboniferous beds, whose intertidal and estuarine habitats are indicated by the occurrence in the same strata of rain pits and sun cracks, such as those described by Sir C. Lyell from the Cape Breton coal district.† Another form of Annelide, *Spirorbis Carbonarius*,

* For fuller information see my paper already referred to, *supra*, p. 42.

† Observed by Mr. Richard Brown, "Manual of Elem. Geology," 5th Edit., p. 384.

appears to have lived on the stems and branches of trees the roots of which were immersed; but its shell is also found in the black shales of the Lower Coal-measures, and in limestone bands of the upper division of this formation.

CHAPTER III.

THE PLANT-REMAINS OF THE CARBONIFEROUS PERIOD.

(*Revised by Professor Williamson, F.R.S.*)

THE vegetable origin of coal was recognised as far back as 1785 by the philosopher Hutton,* and is demonstrable, not only by its microscopic structure, its combustible properties and chemical composition, but also by certain phenomena which may generally be observed in reference to its position in the strata.

Of the two theories of the formation of coal, the first, which refers its origin to drift-wood carried down by streams, and imbedded in estuaries, is certainly inapplicable to the vast majority of coal-seams; the second, according to which the vegetable materials grew on the spot where we now find them in the form of coal, is the only one which is in harmony with

* James Hutton, "Theory of the Earth," Trans. Roy. Soc. Edinburgh, 1785.

the phenomena which generally present themselves amongst British coal-measures.

The subject will be more intelligible to the reader if he become in some degree familiar with a few of the leading members of that luxuriant flora which flourished in the Carboniferous period.

That we have only fragmentary examples of the plants of this period must be evident; for although vegetation attained a vigour which has never before or since been equalled, yet the number of species of coal-plants as yet determined is only about one-twentieth of that of living plants now growing over Europe alone. The number of species noticed by Adolphe Brongniart was 500, which are classified as follows: *—

Thallogens = Cellular cryptogams		6	species.
Acrogens = Vascular	Do.	346	,,
Gymnosperms		135	,,
Doubtful		13	,,

This number has since been increased by Professor Göppert, who estimates the known species of fossil plants of the Carboniferous period to be 879; these he classifies as follows:—

Cellulares, including Fungi, Algæ, etc., 13 species.

* "Histoire des Végetaux Fossiles." (Appendix D.)

VASCULARES, 866 species, of which 772 are *Cryptogams*, or Ferns, Calamites, Lepidodendra, Sigillariæ, etc.; and 94 are *Phanerogams*, such as Conifers, etc.

It must be borne in mind, however, that but little reliance can be placed upon these figures, since very few of the recognised species can be accepted as accurately determined.

The cellular Cryptogams are few in number, and of doubtful character; the great majority of the fossil plants of this period belong therefore to the vascular Cryptogamic class; the gymnosperm Phanerogams and Coniferæ are also represented in the Carboniferous flora, but by a much smaller proportion of species.

The perishable nature of plants under moisture, or water, is perhaps the principal cause of the fewness of the species preserved. It is probable, however, that individuals of a few species predominated very largely, as is the case now in our pine forests, and in the great cypress swamps at the mouth of the Mississippi. Dr. Lindley, by a very interesting experiment, thought that he had arrived at a clue to account for the large predominance of certain classes of plants amongst those which have been preserved. By immersing in cold water for two years a large number of plants, as nearly as

possible representatives of those of the coal-measures, he obtained the following results. He found that the dicotyledonous plants are in general incapable of resisting decomposition when immersed for two years, with the exception of the Coniferæ. 2ndly, That monocotyledonous plants are less liable to decomposition, but that grasses and sedges perish rapidly. 3rdly, That fungi, mosses, and equisetums disappear, while ferns have a great power of endurance, the effect of immersion being only *to destroy all traces of fructification;* a satisfactory reason why fossil-ferns seldom present this portion of their structure, though the fronds themselves occur in great numbers, and in admirable preservation.*

There appears to have been an uniformity in the vegetation of the coal-period, to which there is now no parallel. The same genera, and many of the same species, ranged throughout the whole of Europe, and of North America from the Arctic regions as far south as the thirtieth parallel, that is to say, over a space comprehending about forty-five degrees of latitude; and this uniformity of vegetation is continued vertically, for we find the same species ranging

* Lindley and Hutton: "Fossil Flora," vol. iii.

throughout the whole series of strata, sometimes amounting to a thickness of at least 14,000 feet.

But perhaps the most inexplicable phenomenon in connection with this subject is the occurrence of coal and Carboniferous plants in the Arctic regions. They have been brought from Melville Island, in lat. 76°. Specimens of coal, fossil-wood, and shells belonging to Carboniferous types have been brought to this country by Sir E. Belcher from Albert Land, in lat. 78° of the western hemisphere, and by Mr. Lamont from Spitzbergen, in about the same parallel in the eastern, where the country is described as frightfully barren and desolate, and entirely destitute of vegetation, with the exception of saxifrages, reindeer moss, and similar dwarfish plants. Reasoning from analogy, we could never have supposed that in latitudes now subject to the severest frosts throughout the greater part of the year, and even to deprivation of light for a long period, a vegetation could have flourished allied to that of the tropics, or at least to that of the warmer temperate zones of the present day. But recent investigations have shown that even in the Miocene age the same regions developed a vegetation like that of our

warmer and temperate regions. In many respects the Carboniferous period was certainly a remarkable one, especially in the almost universal diffusion of such plants as Calamites, Sigillaria and Lepidodendron. From all this it would appear that the climate resembled one in which the temperature was free from extremes, rather than that of the equatorial regions.

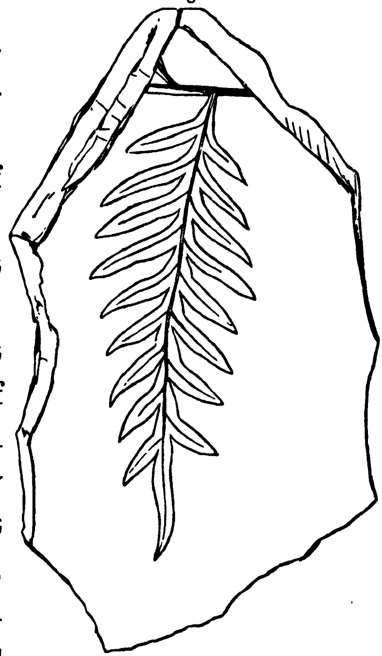
Of the plants that are commonly preserved to us, the ferns seem to take the lowest rank, and the coniferæ the highest; *Calamites*, *Sigillaria* and *Lepidodendron* occupying intermediate positions.* The ferns constituted a most prolific class, occurring in vast quantities in the shales which overlie the coal-seams. The Sigillariæ, Lepidodendra, and Calamites appear to have formed the greater mass of coal; and the roots of the two former (Stigmariæ) penetrate in vast quantities the under-clays or floors of the coal-seams. Coniferous trees, however, formed at some localities a considerable portion of the

* Dr. J. D. Hooker "On the Vegetation of the Carboniferous Period." Mem. Geol. Survey, vol. ii., p. 395. See also "Lectures on the Fossil Plants of the Coal-measures," by Prof. W. C. Williamson, F.R.S., Proc. Roy. Soc., vol. xxvi., p. 411 (1877), and "Observations on the Structure of Fossil Plants of Carboniferous Strata," by E. W. Binney, F.R.S., Palæont. Soc. 1867-72, Parts i., ii., and iii.

mass of the coal, but they seem to have grown on higher and dryer ground than that on which the more characteristic plants above mentioned flourished. I now proceed to give a short description of the genera which have been most prolific and characteristic amongst the flora of this ancient period.

FERNS. — These form a very large proportion of the Carboniferous flora; and, with the exception of their fructification, which has almost always disappeared, are preserved in great perfection. Some of them are represented at the present day by the aborescent forms of the Tropics, which flourish in Ceylon, the islands of the Pacific, and the Indian Archipelago, where they are so abundant as to equal in numbers the whole of the phanerogamic plants.

Fig. 1.



Alethopteris lonchitica.
Portion of frond; two thirds nat. size. From a specimen in the Natural History Museum, Manchester.

The most abundant species in British Coal-measures are: *Alethopteris* and *Pecopteris*.* Of the 140 supposed species known in Britain, 50 occur in the same formation in North America, some ranging from Nova Scotia as far south as latitude 35°.† It is, however, to be remarked that we know little of the habits of the ferns of the coal-period, whether they grew out of the ground, or were parasitic on the trunks of trees; and it is even extremely uncertain what proportion of the large assemblage of fronds belonged to tree-ferns, as we never find the fronds attached to their stems; and the stems themselves are of extreme rarity.

CALAMITES.—This is an abundant genus, and was considered by Brongniart to be represented in our day by the *Equisetaceæ*, of which the horse-tail of our swamps and ponds is a familiar example. Many continental botanists believe that these plants were Gymnosperms; but there is much reason for accepting Brongniart's conclusion, though it is equally certain that whilst the common specimens are merely inorganic casts of a hollow fistular medullary cavity, this medulla

* I omit Cyclopteris, as it is still uncertain whether it belongs to the fern tribe. Mr. Salter believed it to be the leaf of a conifer. See "Geologist," vol. iii.

† Hooker. *Ibid., supra cit.*, p. 52.

was invested by an exogenous vascular zone, enclosed within a rather complicated bark, the two latter structures having often attained to considerable thickness. When young they gave off verticils or twigs, but at a more advanced growth only a small number of these developed into large unsymmetrical branches. The leaves appear also to have been verticillate, but they are difficult of identification; very different plants being included in the genera termed Calamites, Sphenophyllum and Asterophyllites. But little is known of the fructification of Calamites.

This family extends from Lapland to the Equator, attaining the greatest number of species in the temperate zone. The fossil genera differed from the recent in the absence of the encircling sheaths at the joints. The Calamites frequently attain a length of twenty feet.

SIGILLARIA AND LEPIDODENDRON.—These two genera are believed by all British Palæo-botanists to belong to the same Lycopodeaceous group. On the other hand, some Continental botanists distinguish them—regarding the former as a genus of Gymnosperms, whilst the latter they agree with British botanists in regarding as

Lycopodeaceous. The internal organization of the two genera, however, corresponds so closely as to render the separation into two groups unjustifiable. In a large number of the known forms the internal organization is Lepidodendroid in its young state, and only assumes the conditions which Continental botanists, especially of the French School, regard as characteristic of Sigillaria at a more advanced stage of growth.

The internal organization then varies with age. Usually, in its youngest state, the central axis is a solid bundle of scalariform vessels. This soon opens out into a more or less sharply defined vascular ring which encloses a cellular medulla. After a period which seems to have varied in different species, this vascular cylinder is enclosed by a second, which is developed exogenously, and in which the vessels are arranged in radiating vertical laminæ, separated by true medullary rays, and which was capable of attaining to a considerable size, through its exogenous mode of growth. This vascular cylinder was enclosed within a very thick bark separable into three layers, the inner and outermost ones being composed of parenchymatous cells, whilst the intermediate one consisted of a union of bast-fibres

and other oblong cells, forming a modified corky layer. The leaves of Sigillaria and Lepidodendron are undistinguishable from one another. Externally the bark exhibits two very different conditions. In the most extreme Sigillarian type it is fluted longitudinally, the raised ribs having impressed upon them at varying intervals the seal-like scars left by the fallen leaves. In the opposite or Lepidodendron type, these leaf-scars are arranged in diagonal lines and in close contact, the longitudinal flutings being absent; but numerous forms unite these two extremes.

Sigillaria and Lepidodendron alike attained to noble proportions in the Carboniferous period. Sir Charles Lyell mentions an individual Sigillaria seventy-two feet in length, found at Newcastle,* and a specimen of Lepidodendron from the Jarrow coal-mine was more than forty feet in length and thirteen feet in diameter near the base. Specimens both of Sigillaria and Lepidodendron not unfrequently expand to a diameter of several feet at the base, and from this taper upwards towards the summit. The branching of the fluted Sigillaria is not well understood. That of the Lepidodendroid

* "Elements of Geology," 5th Edit., p. 376.

forms is always of the dichotomous type characteristic of the Lycopods.

Notwithstanding its size, Lepidodendron has been shown by Brongniart to have its representative in the diminutive club-moss (Lycopodium) of our mountain heaths. This tribe is generally trailing; but in the neighbourhood of the tropics there are a few erect species, one of which, *L. densum* of New Zealand, attains a height of three feet.

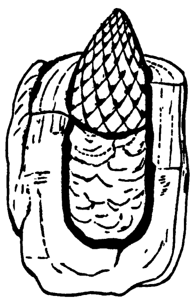
The nature of the root of Sigillaria was first demonstrated by Mr. E. W. Binney, from observations in the Manchester Coal-field, and it is now known that Lepidodendron possesses the same kind of root. The base of each stem subdivides into four large roots, which again subdivides dichotomously into long radiating branches of the well-known *Stigmaria ficoides.* These branches are covered over by multitudes of small circular indentations, from which emanate carbonized rootlets, penetrating the clay in which the rhizomes are imbedded. They were at first supposed to be a distinct genus of plants; but when Mr. Binney discovered, in the neighbourhood of Manchester, several upright stems of Sigillaria attached by their bases to these spreading rhizomes, it

became evident that these portions stood in the relation of stem and root; and fossil-botany now labours under the disadvantage of having two generic names for different parts of the same plant.

The structure of these Stigmariæ is peculiar. Surrounding a small cellular pith, which is often destroyed, is a cylinder of barred vessels disposed in radiating wedges separated by medullary rays, and which has been developed exogenously. Some of the medullary rays are enlarged, and bundles of vessels, derived from the exogenous cylinder, are given off through these enlarged rays to supply the rootlets. It appears that the exogenous cylinder is identical with the outer or exogenous cylinder of the stem. The inner or non-exogenous cylinder of the stem, and from which the foliar bundles are derived, not being prolonged into the roots, the rootlets consist of a small triangular bundle of barred vessels, surrounded by at least three distinct zones of cellular tissue—extensions of corresponding portions of the bark. The latter differs very little from the bark of Sigillarian and Lepidodendroid stems. These stems are frequently found standing erect upon the coal, traversing the

superincumbent strata. Several stems were found standing on the upper surface of a coal-seam at Dixonfold, near Manchester, and some five examples are in the Museum of Owen's College, Manchester.

Fig. 2.



us ornatus in a nodule of ironstone. In the Bristol Museum. (Hooker.)

In the hollow trunks of Lepidodendra small oval or conical bodies (Lepidostrobi)) have frequently been found, often in numbers. They are evidently catkins or fruit-cones; the outer surface was covered by scales or bracts, within which were contained seeds or spore-cases. See Fig. 2.

When enclosed within the trunk, they are found in an erect position: in other words with their major axes parallel to that of the tree. Dr. Hooker, by a series of careful observations, has shown the Lepidostrobi to be the fruit of the tree itself, and accounts for their presence in the trunks by supposing them to have been washed in by heavy rains and floods when the trunks themselves were standing hollow and decayed.*

* In Lord Stamford's museum at Enville there is a specimen of Lepidodendron, collected by Mr. H. Beckett, containing three species of bivalve shells.

LYCOPODITES.—This was a genus of plants allied to *Lepidodendron*, or probably belonging to it, with pinnated branches, and leaves inserted all round the stem in two opposite rows, not leaving clean and well-defined scars.

The genus *Knorria* of Sternberg no longer exists as such, according to the view of Prof. Göppert, who has suggested that it is only a form of *Sagenaria* or *Lepidodendron*; and that the most common species in the Lower Carboniferous rocks, *Knorria imbricata*, belongs to *Sagenaria Weltheimiana*.*

There is now little doubt but that these plants are merely examples of a Sigillarian or Lepidodendroid bark from which the outer layers have become detached.

ULODENDRON.—A plant of which the affinities were long uncertain. It is now clear that it is a Lepidodendroid tree, and that the peculiar, large, round or oval scars, which are arranged in two vertical rows on opposite sides of the branches, are areas from which Lepidostrobi have been detached. These cones have recently been found *in situ*.

ASTEROPHYLLITES, SPHENOPHYLLUM, and ANNU-

* "Ueber die fossile Flora der Silurischen der Devonischen und unteren Kohlenformation," 1859.

LARIA.—These are plants with verticils, or small leaves. Some of them are probably Calamitean. Others, especially Asterophyllites and Sphenophyllum, bearing fruit-spikes known as Volkmanniæ, etc., are more probably Lycopodeaceous.

CONIFERÆ.—It is not without interest that coniferous trees formed a very important part of the flora of this ancient period of the world's history; so that, as remarked by Sir C. Lyell, their presence precludes us from characterizing the Carboniferous flora as consisting of imperfectly developed plants, the Coniferæ taking a high, though not the highest, position in the ranks of vegetable organization.*

The prevalent type seems to have been that of the Araucarian or Norfolk Island Pine; but seed-cones resembling those of the genus *Pinus* have also been found. One specimen from the Newcastle coal-field is figured by Lindley.†

* "Elements," p. 374. The late Mr. Hugh Miller has demonstrated the existence of Coniferæ at a much earlier period—that of the Old Red Sandstone of Scotland. See "Footprints of the Creator," p. 199. Prof. Göppert has recently shown that the Coniferæ make their appearance amongst the upper Devonian rocks.—Journ. Geol. Soc., vol. xvi.

† "Fossil Flora," vol. iii., p. 43.

The Coniferæ of the Coal-period differed from those of the present day in the large size of their pith; and the remarkable, and for a long time inexplicable, fossil, found generally in sandstones, known as *Sternbergia*, has been demonstrated by Professor Williamson to be an inorganic cast of cavities within the pith of these trees.

The little ribbed nodular mass, *Trigonocarpum*, found in great numbers throughout the Coal-measures, formerly considered as the fruit of a palm, is now known to be the inorganic cast of the interior of the "testa" or integument of a seed which probably belonged to a Coniferous plant. Like those of the Chinese *Salisburia adiantifolia*, this seed had a hard inner shell, invested by a fleshy envelope, the two enclosing the kernel, which has usually disappeared. The broad leaves designated *Nœggerathia*, formerly regarded as palms, are now known to belong to the genus *Cardaites*, which possessed spikes of unisexual flowers. The plants termed *Antholithes* are the flower spikes, and the seeds known as *Cardiocarpon* are those of some species of this group. These plants display both Coniferous and Cycadean affinities. No traces of palms have been found in the Carboniferous strata,

all the plants formerly regarded as such being known to belong either to the Ferns, or to the Gymnospermous group.

The flora of the "Culm," belonging to the Lower Carboniferous series of Devonshire, contains twenty-three species, of which one plant is marine.

These details may appear to some uninteresting; but they serve to show how necessary is a large acquaintance with the vegetation of the present, before we can rightly understand that of the past. An acquaintance, however varied, with the recent botanical productions of our own country, would tend to throw little light on the nature of that flora which flourished upon the same spot so many ages back. The tropics, and even the diametrically opposite portions of the earth, as New Zealand, Australia, and Norfolk Island, have to be searched in order to furnish analogous productions; and where these are sought for in vain, as in the case of several Carboniferous genera, we find it difficult to picture before our minds those bygone structures of which we possess but the defaced ruins.

We have only here described those forms which were most prolific—many more must have

existed of which we have no trace.* We may, however, fully accept the opinion of Hugh Miller, that this was "a flowerless vegetation." We feel pretty certain on other grounds than the mere absence of their remains, that those orders of plants which refresh our senses with their flowers and fruits (as these terms are commonly understood) existed not in the true Coal-period. There is every reason for believing that the *Rosaceæ*, *Leguminoseæ*, and a few other tribes adapted to charm the eye and minister to the wants of man, only appeared as the harbingers of man himself; therefore, with all the luxuriance of the foliage, and the denseness and stature of the trees which overspread the great lagoons of the Carboniferous period, the general effect must have been sad and sombre in the extreme. But it persisted, through long ages, in unspeakable loneliness and silence, echoing neither voice nor sound, except when some giant of the forest snapped in twain, and fell heavily into the arms of its companions.

* A large number of species of Gymnospermous seeds, many of them of remarkable dimensions, have been found both in England, France, and America, whilst we have no clue whatever to the important trees to which they belonged.

CHAPTER IV.

FORMATION OF COAL.

When Sir William Logan, thirty years ago, was engaged on his great survey of the coal-field of South Wales, he found it to be an invariable rule that every coal-seam reposed on a bed of clay (underclay) penetrated by the rootlets of *Stigmaria ficoides.** This observation has been extended to every coal-field in Britain ; and although the character of the underclay varies considerably, sometimes becoming a hard siliceous stone, yet the presence of the carbonized rootlets shows that it has borne the same relation to the coal as have the softer underclays. This observation of Sir W. Logan established the hypothesis that the plants of which coal is formed grew upon the spot where we now find them mineralized, and that the underclays formed the soil from whence they sprung.

Now these underclays are distinctly stratified, showing that they have been deposited under

* "Geological Transactions," 2nd series, vol. vi.

water; and hence it was supposed that in order to become the receptacles for the growth of luxuriant forests, they must have been elevated into dry land; and then, after having been covered by vegetation, were again submerged to be overspread by sands, clays and other sedimentary materials which combine to form the strata of the Coal-measures. This theory required a series of oscillations over a large extent of the earth's surface, which seemed rather improbable, and not in accordance with observations on changes of level which have been made in various parts of the world. That there are slow elevations, and subsidences of the surface in operation more or less extensively, is proved by phenomena exhibited on our sea-coasts,* where in some cases old sea-beaches are found at elevations far beyond the reach of the waves, and in others where forests, and even towns, are known to have been engulfed; and the whole of the geological record teaches us that similar vertical movements have been taking place from the earliest periods.

Along the eastern coasts of South America, Mr. Darwin has described the existence of a succession of terraces, rising in tiers from the

* For many examples, see Lyell's "Principles of Geology."

sea-level up to an elevation of 1,200 feet. He has shown that each of these terraces has in turn been for a long period subjected to the action of the waves, which has swept away a vast quantity of material, and hollowed out caverns in the rock.*

Now, as the whole of the land, from the highest terrace down to the level of the ocean, has evidently been under the sea, to have attained its present position it must have been elevated, and each coastline marks a pause in the process of elevation. Here is an example of a constant change of level, with pauses; and it probably furnishes an illustration of Nature's mode of action during the coal-period. The process, however, in this case must be *reversed*, and instead of periodical elevations it is necessary to infer a slow and gradual subsidence of the sea-bed, accompanied by pauses marked in many cases by the formation of a seam of coal.†

But another question requires elucidation.

* "Voyage of the Beagle," vol. iii., p. 200.

† This illustration has previously been employed by Mr. Binney, to whom, more than to any author, we are indebted for our present knowledge of the circumstances under which coal has been formed. It is, however, so apt, that I have no hesitation in producing it here.

The coal-seams are associated with strata deposited under water; and all recent investigation strengthens the probability that this water was generally fresh, sometimes estuarine, or marine. In the northern coal-fields of England, some of the coal-seams are covered by black shales, containing remains of fishes and marine shells, as *Goniatites*, *Aviculo-pecten*, *Orthoceras*; and along the coast of Dunbar, in Scotland, bands of limestone, with marine shells, as *Spirifer*, *Productus*, etc., rest upon coal-beds, and on the upright stems of Sigillaria.* In coal-measures belonging to the higher portion of the Carboniferous series, bivalves which were formerly supposed to belong to the fresh-water genus *Unio*, have since been found in the same stratum with *Modiola* and *Aviculo-pecten*. For this genus we adopt the name *Anthracosia* of Professor King,† and believe it to have lived in seas, estuaries, or lakes. Mr. Binney has shown the probability that the little coiled shell (*Microconchus carbonarius*) is in reality a coiled

* These limestones contain fossil representatives of the Carboniferous limestone of England; and it is well known that a portion of the coal-measures of Scotland are of earlier date than those of England.

† Annals and Magazine of Nat. Hist., Jan., 1855.

Serpula or *Spirorbis*, which attached itself to the coal-plants; * and lastly, the minute crustacean abundant in coal-shales, and supposed to have belonged to the fresh-water genus *Cypris*, is with more probability referred to the marine genus *Cythere*. Whilst admitting, therefore, the prevalence of lacustrine strata in the upper part of the coal-measures, I think we may conclude that the formation has been in part of marine and estuarine origin—a conclusion at which we might arrive on other grounds, when we consider that the formation was at one period continuous over the greater part of Central North America, and would have required for its generation a lake of a size at least six times the area of all the great lakes of that continent united.

There are two conclusions which strike us most forcibly when reflecting on the formation of our coal-fields;—the enormous subsidence of the original surface, and the lapse of time it must have required to produce a series of strata, with their coal-seams, in all, several thousand feet in thickness.

Recollecting that every bed of true coal *repre-*

* It is scarcely necessary to remark that Serpula is a marine annelid.

sents a land-surface, or at least a sea-level, when we find, as in the case of the coal-field of South Wales or of Nova Scotia, strata with coal-beds through a thickness of 10,000 or 12,000 feet, it is evident that this is a measure of the actual sinking of the surface for this one geological period; or, to take an example:—the height of Mont Blanc is about 15,000 feet; now the vertical displacement which the South Wales coal-field underwent was nearly sufficient to have brought the summit of the Alps to the sea-level.

Of the lapse of time in the formation of our coal-fields we can have but a faint conception; it is only to be truly measured by Him with whom "a thousand years are as one day." But the magnitude of the time is only surpassed by the boundlessness of the providential care which laid up these terrestrial treasures in store for His children, whom He was afterwards to call into being. Let me therefore dismiss this subject with one illustration. Mr. Maclaren, by a happy train of reasoning, for which I must refer the reader to his "Geology of Fife," * arrives at the conclusion that it would require a thousand years to form a bed of coal one yard

* Page 116.

thick. Now, in the South Wales coal-field there is a combined thickness of coal amounting to one hundred and twenty feet, or forty yards, which, according to this hypothesis, would have required a period of 40,000 years for its formation. If we now assume that the 12,000 feet of sedimentary material was deposited at the average rate of two feet in a century, corresponding to the rate of subsidence, it would have required $\frac{12000 \times 100}{2} + 40,000 = 640,000$ years to produce this coal-field.*

I have spoken of the difficulty of conceiving frequent *elevations* of the sea-bed during the long period of subsidence in order that a land surface might be laid dry for the growth of vegetation. A much more probable supposition is, that the coal-plants were fitted to grow with roots and stems partially submerged. Analogy would

* In this estimate I have adopted a medium between two extreme estimates given by Lyell, "Elements," pp. 386, 387. For a good *résumé* of this subject, see Jukes' "Manual of Geology," p. 95, *et seq.*

The late Professor Phillips attempted a calculation of the time required for the production of this coal-field founded on the supposition of the sedimentary materials having been formed at the mouth of a large river, such as the Ganges, and the carbonaceous portions having been stored up at the rate of one inch in 127·2 years; the result arrived at being about half a million of years.—"Life on the Earth," p. 134.

lead us to this conclusion in the case of *Sigillaria*, *Calamites*, etc., and among the dense forests of larger trees there may have been an undergrowth of reeds and grasses.

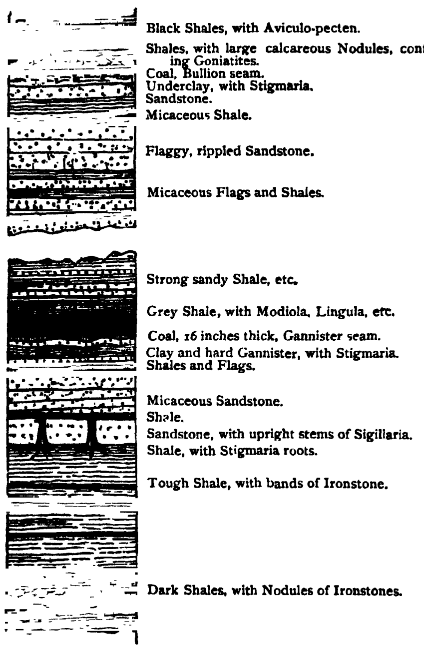
The great swamps at the estuary of the Mississippi, and those along the coasts of Louisiana, Nova Scotia, and the tropical lagoons of the African coast, furnish us with the nearest representations of the nature of those forests that have produced our coal-beds; but none of them are strictly analogous. The physical conditions of the coal-period stand alone, and we cannot but conclude that they were ordained beforehand for a great and evident purpose.

The strata which are associated with the coal consist of sandstones, which were once sand; shales and fire-clays, which were once fine mud. Some of the shales are so highly carbonaceous as to be nearly black, and form impure coal called "bass." Bands of limestone occur in the higher beds of the coal-measures in England, and throughout the greater portion of the formation in Scotland.

The sandstones are frequently rippled, and obliquely laminated, showing the prevalence of currents; they also contain fragments of drifted plants. The shales are generally laminated, show-

ing a slow and tranquil deposition. The general succession of strata which accompany coal is shown in the annexed section, taken from the neighbourhood of Wigan, and belonging to the lower coal measures, or Gannister series.

Fig. 3.
Succession of Strata in Lower Coal-measures, near Wigan, Lancashire.



Of coal, as a mineral, I must here say a few words. All the coal of the older formations, except the better sorts of "cannel," presents, in a cross-section, a truly laminated aspect, and consists of layers of glossy, bituminous coal, alternating with thinner bands of anthracite. The former class presents no trace of organic structure; while in the latter, under the microscope, the various tissues of Araucaria,

Sigillaria, and other plants, as well as their fructification, may be detected.

There can be no doubt but that this laminated structure is the result of accumulation under water; and Bischof * adopts this view upon other considerations. He says, "The conversion of vegetable substances into coal has certainly been effected by the agency of water." The same great authority believes that coal has been formed, not from the dwarfish mosses, sedges, and other plants which now contribute to the growth of our peat-bogs, but from the stems and trunks of the forest-trees of the Carboniferous period, such as Sigillariæ, Lepidodendra, and Coniferæ.

The earthy portion of coal, which after combustion forms ash, is disseminated in minute particles throughout the entire mass, which could only have occurred by infiltration; but before woody fibre is in a state to admit of the infiltration of sediment mechanically suspended in water, it must have undergone partial destruction. Hence we may conclude that, as the forest-trees successively fell through age or accident, they were immersed in water—which

* "Chemical Geology," vol. i., Messrs. Paul and Drummond's Trans.

must have been shallow, and which held in suspension particles of clay or sand. Mr. H. Taylor gives the following analysis of the ash of a good coal-seam from Newcastle:—

Silica	59 · 56
Alumina	12 · 19
Peroxide of iron	15 · 96
Lime	9 · 99
Magnesia	1 · 13
Potash	1 · 17
	100 · 00

Bischof has shown that this analysis does not much differ from that of many of the shales with which the coal is associated.

The conversion of wood into coal may take place in four different ways; namely,—

1. By the separation of carbonic acid and carburetted hydrogen.
2. ,, ,, carbonic acid and water.
3. ,, ,, carburetted hydrogen and water.
4. ,, ,, carbonic acid, carburetted hydrogen and water.

And from the mean of 67 analyses given by Bischof, it appears that by three of these processes the wood

Lost	and	Yielded.
In 1—78 · 0 per cent.		22 · 0 per cent. of coal.
In 2—57 · 3 ,,		41 · 7 ,, ,,
In 3—45 · 5 ,,		54 · 5 ,, ,,

The copious discharge of carbonic acid and carburetted hydrogen given off by wood in its conversion into coal, appears to have taken place for the most part during the progress of decomposition in the coal-period; for it has been found by a comparison of the analyses of true coal with the lignite of the Tertiary strata, that the difference in the percentage of oxygen and hydrogen in these two classes of minerals is not very great. In lignite the oxygen is only 1·54 per cent., and the hydrogen only 0·38 per cent. more than in true coal. It would therefore appear that, in the long lapse of time between the Carboniferous and Tertiary periods, the coal experienced an extremely slight loss of substance. In the coal-fields these gases are constantly escaping in jets from the shallower seams; but in the deeper parts are pent up at an enormous pressure, and by their elastic force materially assist the miner in his excavations.

Analysis of 8 *Specimens of Coal from Newcastle, Glasgow, Lancashire, Edinburgh, and Durham (Bischof).*

Carbon.		Hydrogen.		Oxygen & Nitrogen.		Earths.	
Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
89 · 2	79 · 1	7 · 2	5 · 3	14 · 5	5 · 5	2 · 9	0 · 5

*Analysis of Anthracite from Pembrokeshire, by Schafhäult.**

Carbon.	Hydrogen.	Oxygen and Nitrogen.		Earths.
94 · 10	2 · 39	1 · 34	0 · 87	1 ·30

* Dana's "Mineralogy."

*Analysis of Brown Coal (Lignite), from Elbogen.**

Carbon.	Hydrogen.	Oxygen & Nitrogen.	Earths.
73 · 79	7 · 46	13 · 79	4 · 96

Of Britain it may be emphatically said, "whose stones are iron, and out of whose hills thou mayest dig brass." Clay-ironstone abounds in the shales of every coal-field, either in the form of nodules or in thin courses. She has also erected more altars to Vulcan than any other country, and the products of her Carboniferous rocks—the coal, ironstone, and limestone—have enabled her to take the foremost place in the industrial arts.

The coal-formation is very frequently traversed by vertical fractures or *faults*, which, within a few yards or feet, completely change the series of strata and the mineral character of the district. These faults are actually vertical dislocations of the rocks, the beds having been upheaved or depressed, as the case may be, tens, hundreds, or even thousands of feet along the line of fracture. Many examples will be produced when I come to treat of the coal-fields; but I may mention that some of the faults which traverse the coal-districts of Lancashire and Staffordshire dislocate the strata to the amount of 600,

* Phillips' "Mineralogy."

700, or even 1,000 yards! How graphically has that grand old geologist, the patriarch of Uz, described these throes of our great mother Earth when he says: "He putteth forth His hand upon the rock, He overturneth the mountains by the roots!"

The Coal-measures of England rest upon a series of hard and coarse sandstones and shales —called "Millstone Grit"; this again on a thick series of shales and grits, "the Yoredale rocks," which pass downwards by the intermixture of courses of limestone into the great calcareous deposit, the Carboniferous Limestone. This last formation attains in Derbyshire a thickness of 5,000 feet, and is surcharged with marine fossils throughout; indeed, it is almost wholly composed of the shells of mollusca, the calcareous habitations of corals, or the broken skeletons of Crinoidea or "stone lilies." These last must have covered the bottom of the ocean in countless myriads, forming miniature forests, which rose generation after generation upon the accumulating layers of their perished ancestors, until their remains were sufficient to form thick beds of limestone, extending for many miles in every direction. In some parts of Derbyshire and Yorkshire the limestone appears to be composed

of little else than the disjointed skeletons of Crinoidea.

The Coal-measures are overlaid by the Permian formation, consisting of three members: the lower composed of red and purple sandstones, marls, calcareous conglomerate, and breccia; the middle, of magnesian limestone of the north-eastern counties; the upper, of gypseous marls and sandstones. This formation is unconformable to the Coal-measures, and to the Trias which succeeds it.

Next in succession is the Trias, or New Red Sandstone, which, in the absence of the Permian strata, sometimes rests directly upon the Carboniferous rocks. It consists of two members, the Bunter and Keuper; the middle member, the Muschelkalk, being absent in Britain.

The Bunter Sandstone consists of three members: the lower, soft red and variegated sandstone; the middle, quartzose conglomerates and red pebbly sandstone; the upper, soft-streaked and variegated sandstone. Upon this the Keuper series rests unconformably, the upper surface of the Bunter Sandstone being frequently eroded and waterworn. The Lower Keuper Sandstone is introduced by calcareous breccia, and passes upwards into the Red Marl.

We are now in a position to comprehend in some measure the formation of a coal-seam in olden time.

Let us suppose that a certain bed of coal has been completed by the growth of luxuriant plants over a low-lying tract subject to inundations. Rising ground of granitic, schistose, or Lower Palæozoic rocks in the distance defines the margin of the basin, and the boundaries of a continent from which the sedimentary materials of the coal-strata are derived. That growth of vegetation marks a period of rest; but now a slow subsidence of the whole tract commences. The brackish waters of the estuary, or the salt waters from the ocean, invade the jungle, carrying dark mud in suspension, with floating stems of trees and fronds of ferns. Presently the mud subsides, and covers in one uniform sheet the accumulated vegetation of centuries. The process of subsidence goes on, while the river-currents pour into the estuary fine sand and mud, in which branches and stems of trees from the uplands are often included. This process continues until the sinking of the ocean-bed either altogether ceases, or is counterbalanced by the rapidity with which the sediment is deposited. The basin becomes gradually shallower, and the plants begin to reappear, commencing perhaps

at the margin, and creeping outwards until the whole basin is again overspread by a forest of huge cryptogamic trees, aborescent ferns, and tall conifers. These, generation after generation, flourish and die; their leaves, branches, and trunks falling around, and gradually accumulating till the pulpy mass attains a thickness of 20, 50, or 100 feet. The process concluded, the basin again commences to subside, the waters return and bury the mass for, perhaps, hundreds of years; stratum after stratum accumulates, till the vegetable pulp is subjected to the pressure of, it may be, thousands of feet of solid matter. Meanwhile, chemical, as well as mechanical, changes ensue, and in process of time what was once a forest is changed into a bed of coal. By a repetition of this process, with local variations, we may conceive the formation of any number of coal-seams, amounting, in some districts, to fifty or sixty, and embraced within a vertical thickness of several thousand feet of shales, clays, and sandstones. Ages roll on, the strata are moved from their foundations; upheaved into ridges and plateaux, the rains, rivers and currents sweep away a portion of the covering, and the mineral treasures are brought within the reach of mining industry.

CLASSIFICATION OF CARBONIFEROUS AND NEIGHBOURING FORMATIONS.

The following view of the formations which lie immediately above and below the Coal-measures may prove useful for reference. It is applicable, I believe, to the whole of Britain. The tripartite division which I have adopted for the Coal-measures of England and Wales is not, as yet, generally recognised, but every day's experience tends to make the necessity for such a division more than probable.

Tabular View of the Triassic, Permian, and Carboniferous Series in England and Wales.

New Red Sandstone or Trias.	Keuper . .	Red marl. Lower Keuper sandstone, with calcareous breccia in lower part (Somersetshire, etc.)
	Bunter . .	Upper mottled sandstone. Conglomerate beds. Lower mottled sandstone.
Permian Rocks		Upper red sandstone of St. Bees', etc. Upper and lower magnesian limestones and marls of the Northern Counties. Lower red sandstone of Lancashire, Cumberland, Yorkshire, etc. (on the same horizon with) Red sandstones, marls, conglomerates, and breccias of the Central Counties and Salop. (Rothetodte liegende.)

Carboniferous Rocks.	Upper Carboniferous	Upper Coal-measures, with 'Spirorbis limestone' and thin coal-seams.
		Middle Coal-measures, with thick coal-seams.
	Middle Carboniferous	Lower Coal-measures or Gannister series, with thin coal-seams and marine fossils.
		Millstone grit, with thin coal-seams.
		Upper limestone shale or "Yoredale rocks," with marine fossils.
	Lower Carboniferous	Carboniferous limestone with marine fossils.
		Lower limestone shale, or Calciferous sandstone series, fossils marine.*
Old Red Sandstone . . .		Kiltorcan beds with *Anodonta Jukesii* in Ireland (Lacustrine).
		Old red sandstone and conglomerate. "Pickwell Down sandstone" of Devonshire (Lacustrine).
Devonian Rocks		Marine beds of Ilfracombe and Lynton (absent in Ireland and Scotland). (Represented by the "Cornstone series" of Herefordshire).
		Upper Silurian rocks.

In examining the Fauna of the Carboniferous series from its base upwards over the British and adjoining Continental areas, we shall find that we ascend through a vast series of essentially marine strata, with oceanic beds like those of

* In Ireland the Coomhola grits and Carboniferous slate belong to this division, and in Devonshire "the Barnstaple," "Pilton," and "Marwood beds." (Quart. Journ. Geol. Soc., May 1880, p. 262.)

the Carboniferous Limestone, until we reach the top of the Gannister beds, or Lower Coal-measures of England, where a change occurs in the character of the fossil-forms, and the marine organisms give place to those of fresh water or estuarine characters. Upon this change in the character of the Fauna the above classification of Lower, Middle, and Upper Carboniferous beds is based—the foundation of the whole series being the Lacustrine beds of the Old Red Sandstone of England, Ireland, and Scotland, with its peculiar Fauna and Flora. Thus the Lower and Middle Carboniferous beds form a marine series interposed between the lacustrine beds of the Old Red Sandstone on the one hand, and those of the Upper Carboniferous series on the other. The following table (p. 86) will show the representative beds according to this classification over the area above stated.*

Having thus given a brief sketch of the nature of coal, its origin, and the strata with which it is associated, we are now prepared to pass on to the consideration of the coal-fields themselves.

* This classification is in conformity with the views I have put forth in my paper "On the Upper Limit of the Essentially Marine Beds of the Carboniferous Group of the British Isles," etc. (Quart. Journ. Geol. Soc., Nov. 1877.)

TABLE OF REPRESENTATIVE

	Stages.	England and Wales. North.	England and Wales. South.	Ire- North.
Upper.	G.	Upper Coal-measures of Manchester, etc., Staffordshire, Denbighshire.	Generally absent (through denudation).	Absent (through denudation).
	F.	Middle Coal-measures with thick coal-seams, etc., Lancashire, Yorkshire, Derbyshire, etc.	Middle Coal-measures of South Wales and Somersetshire, etc.	Coal-Island Coal-field, co. Tyrone.
Middle.	E.	"Gannister Beds," or Lower Coal-measures.	Lower Coal-measures, with ironstones and thin coals.	Lower Coal-measures of Drumglas (Tyrone), coal-fields of Lough Allen (co. Leitrim).
	D.	Millstone Grit series, Lancashire, Yorkshire, Derbyshire, etc.	Millstone Grit, or "Farewell Rock."	Millstone Grit of Fermanagh, Sligo, etc. (Cuilcagh).
	C.	Yoredale series, or Upper Limestone shale. "Upper Bernician beds" (Lebour).	Upper Limestone shale (thin).	Ironstone shales of Lough Allen, also of Drumglas (co. Tyrone).
Lower.	B.	"Mountain Limestone" of Derbyshire, "Scaur or Scar" Limestone (Sedgwick).	Carboniferous Limestone of Cheddar, the Wye, Avon, and S. Wales, etc.	Carboniferous Limestone in three divisions. Ballycastle Coal-field, co. Antrim (in part).
	A.	"Tuedian Group" (Tate), often absent in N. Lancashire, etc.	Lower Limestone shale (thin).	Calciferous Sandstone series or Lower Carboniferous Grits.

CARBONIFEROUS FORMATIONS.

LAND.	SCOTLAND.	CONTINENTAL.	
South.	Central.	Belgium and Germany.	Conditions of Deposition.
Absent (through denudation). Leinster Coal-field, from "the Jarrow Coal" upwards.	Upper red sandstones of Bothwell, etc. Ayrshire, beds with Spirorbis Limestone. "Flat-coal" series or "Upper Coal" series of Scotland with thick coals.	Possibly present in the Belgian and Saarbrück Coal-fields. Main Coal-measures of Belgium, Saarbrück, Westphalia, Saxony, and Silesia, etc.	Essentially estuarine and lacustrine, with intrusions of the sea at long intervals.
Lower Coal-measures of Leinster, Modubeagh, Tollerton, Skehana and Slieveardagh, etc. Flagstone series of Carlow, Kilkenny, Clare, etc. "Shale series" of Carlow, Kilkenny, Clare, etc.	Beds on the horizon of "the Slaty-band" ironstone? "Moorstone rock" and Roslin sandstone. "Upper Limestone series" resting on "Lower coal and ironstone series"?	Schistes de Lens, Auchy-au-Bois, Chokier. Bottom shales of the Coal-measures of Silesia, etc. Generally absent in Belgium. Flötzleerer Sandstein of Germany. Calcaire de Visé. Bruchberg crinoidal sandstone (Harz)?	Essentially marine, rarely estuarine. (Sea shallower than in Stage B.)
Carboniferous Limestone, in three divisions. Lower Carboniferous slate (in part) with Coomhola grits.	"Lower Limestone series" of Gilmerton, Roman camp, etc. Calciferous Sandstone series in two groups.	Carboniferous Limestone of Belgium (Calc. de Dinant, Calc. de Tournai), France, Germany, Russia, etc. "Schistes de Tournai," and "Kiesel-Schiefer," etc. "Jüngere Grauwacke" of the Vosges and of the Schwarzwald.	Essentially marine, and deep-sea beds (except occasionally in Scotland, where lacustrine or estuarine beds occur).

PART II.

CHAPTER I.

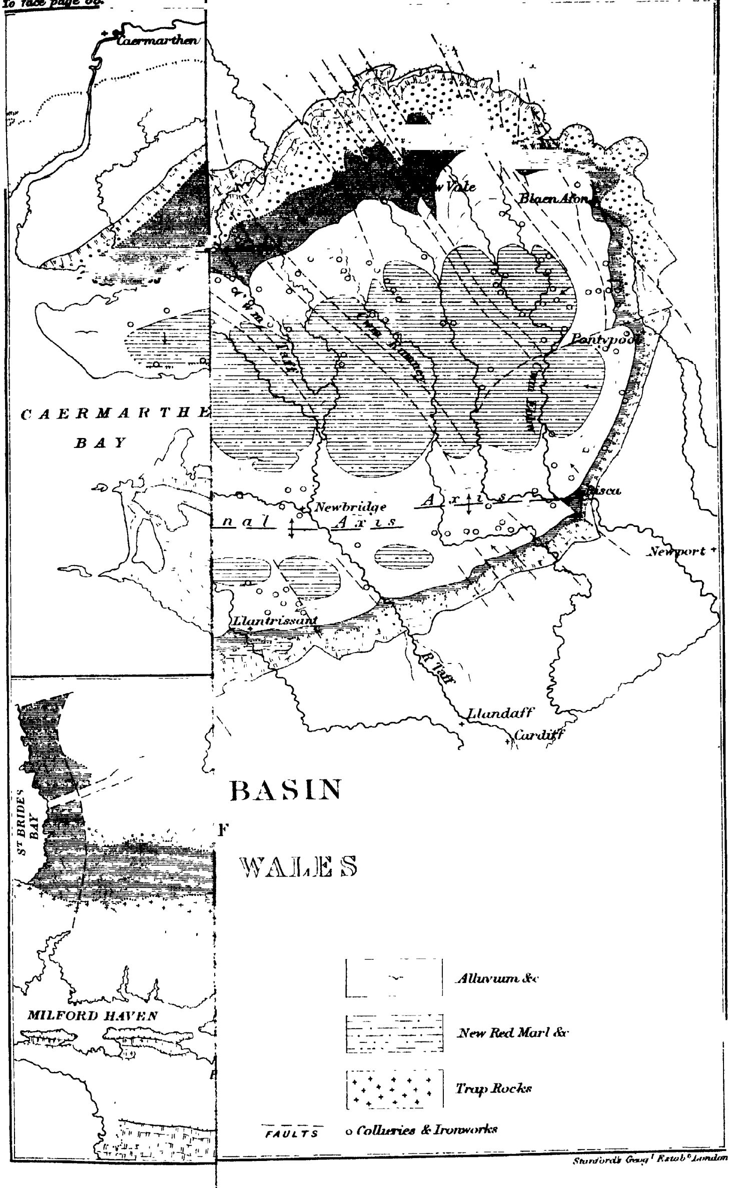
THE GREAT COAL-FIELD OF SOUTH WALES.

THE coal-field of South Wales is, with the exception of that of the Clyde Basin, the largest in Britain, and contains almost as great a vertical thickness of strata as any coal-field in the world, amounting to upwards of 10,000 feet.*

It is separated by Caermarthen Bay into two unequal portions. That to the east of the bay stretches to Pontypool, in Monmouthshire, a distance of 56 miles, and is the larger portion. The smaller extends to St. Bride's Bay, a distance of 17 miles, and is washed by the waves of

* It is a lamentable fact that the iron and coal industries of this great and rich district have been seriously damaged, and in some cases destroyed, by strikes amongst the workmen against reductions in wages in the face of a falling market.

To face page 88.



the Atlantic. The greatest transverse diameter is 16 miles, in the meridian of Neath, in Glamorganshire.

The general form of the coal-field is that of an oval basin or trough, lying nearly east and west. It is deeply indented by the bays of Swansea and Caermarthen, which overspread the upturned edges of the strata as they cross from shore to shore. The beds also rise and crop out towards the north, beyond which the Millstone Grit and Carboniferous Limestone mark the limits of the coal-producing area, often terminating in a series of fine escarpments with northerly aspects.

The coal-field east of Caermarthen Bay is traversed throughout nearly the whole of its length by a remarkable anticlinal axis, which has been traced from the north of Risca, by Pontypridd and Ton-yr-efail, across the Lesser Ogwr, by Nant-Tyrus, the Masteg ironworks, and Aberavon, beneath Swansea Bay.* The basin is thus divided into a northern and southern trough, lying on either side of the great anticlinal axis, and of which the former occupies twice the area of the latter. The effect of this axis is to bring the lower coals

* Mr. H. Hussey Vivian, M.P., and Mr. G. T. Clark, Rep. Coal-Commissions, vol. i., pp. 1 and 9.

within reach of mining operations along a considerable tract of country.*

It is also worthy of note that this line of elevation is so placed as to be nearer to the southern side of the basin, where the dip inwards along the margin is steepest; so that, were it not for the existence of this flexure, the lowest seams (which are of great value) would have been placed at depths far beyond the reach of mining operations, within a comparatively short distance of their actual outcrop. The result of this arrangement of the strata, however, is most favourable for their recovery by mining; as, in consequence of the anticlinal, these seams of coal are brought again either near to the surface, or within depths where they may ultimately be rendered available. The effect of this anticlinal is shown in the accompanying section (Fig. 4, p. 92), across the coal-field in a north and south direction. Another anticlinal axis ranging in a parallel direction enters Caermarthen Bay south of Kidwelly.

Scenery.—Along its northern border, the coal-field partakes of a mountainous character, rising

* This flexure is very well represented on the horizontal sections of the coal-field, published by the Geological Survey, and drawn by Mr. Williams and Sir H. de la Beche.

into lofty tabulated or slightly sloping hills, terminating abruptly towards the northern outcrop of the beds, and indented by deep valleys, which often coincide with lines of dislocation. These valleys, extending inwards in a southerly direction, afford facilities for working the seams of coal by means of adits and galleries stretching far beneath the hills. Beyond the limits of the Coal-measures, the hard siliceous sandstones and conglomerates of the Millstone Grit form an encircling zone; and from beneath these the more splintery beds of the Carboniferous Limestone rise to the surface, and present towards the north a range of scarped terraces, often broken through by valleys and gorges which have been determined by faults, but on the whole preserving a general direction parallel to the *strike* or direction of the beds, and attaining an elevation of 2,000 feet. Along the southern boundary of the coal-field, these Lower Carboniferous formations produce rich and varied scenery, but not of so bold and elevated a character as along the northern margin. From Swansea Bay eastwards, the Pennant Sandstone rises into high terraced hills, with abrupt slopes facing the shore of the Bristol Channel.

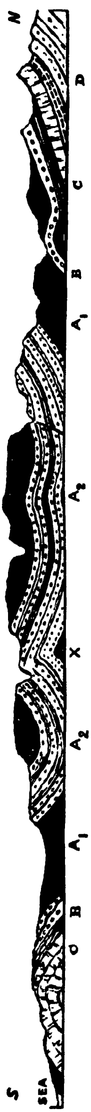


Fig. 4.—SECTION ACROSS THE COAL FIELD OF SOUTH WALES.
Length about 20 miles.

A_1. Coal Measures, with coal. A_2. Pennant Sandstones. B. Millstone Grit. C. Carboniferous Limestone. D. Old Red Sandstone.

As Mr. Clark has justly observed, it is mainly owing to the intersection of the coal-field by the great valleys of the Nedd, Afon, Ogwr, Taff, Rhymney, and Ebbw, and their subordinates, the Ely, Rhondda, Cynon, Sirhowy, and the Afon Llwyd, that there are more than ordinary facilities for working coal economically, as much of it is recoverable simply by driving adits from the out-crop. On this account it is, that the coal-pits are generally shallow as compared with those of the north of England.

Surveys.—As far back as the close of the 16th century, George Owen, a native of Pembrokeshire, drew up a very clear description of the physical features of the South Wales coal-field, tracing the trend of the coal-seams and beds of mountain limestone, and pointing out the relationship of these formations

to their representatives in Gloucester and Somerset.* After the completion of the Ordnance Surveys, the geological delineation at first commenced by Sir E. Logan was subsequently completed by Sir H. T. de la Beche and Mr. Williams, during 1837 and following years. They have left us a series of beautifully-executed maps and sections, presenting the details as far as they were discoverable at a time when the coal-field had been very partially explored by mining operations. Of these documents it was stated by one competent to judge, that they at once placed the proprietors of coal-property in the possession of information which it would have taken thirty years to acquire by the advance of mining enterprise.

More recently a fresh survey was undertaken for the Royal Coal-Commission by Messrs. H. Hussey Vivian and G. T. Clark, with the assistance of Mr. Evan Daniel, of a very elaborate nature, in which the areas of the different groups of coal-seams, according to depth, are represented on eighteen plans; and furnish

* This work was left behind in MS., but was afterwards published in the "Cambrian Register," and reflects the highest credit on the author.

us with a complete anatomy of the structure of the district. This work, accompanied as it is by elaborate tables containing the area, thickness, and quantities of coal in each seam, has been one of more than ordinary labour.

General Succession of Strata, and their thicknesses, in Monmouthshire.

Coal-measures.—Shales, with ironstones; sandstones, including the "Gower series," and *coal-beds*, of which there are about twenty-five more than two feet thick. Total thickness, 11,650 feet.

Millstone Grit (Farewell Rock).—Beds of hard sandstone and conglomerate, with partings of shale (Merthyr Tydvil); thickness, 330 feet.

Carboniferous Limestone.—Upper beds consisting of alternating dark shales with bands of limestone, passing downwards into massive beds of the latter; thickness 1,000 feet.

Old Red Sandstone.—Sandstone and conglomerate; 600 feet.

Devonian Beds (*Estuarine*).—Red and brown sandstone, marls, and calcareous cornstones, thickness 6,000 feet, or less.

Westward of Swansea Bay the Millstone Grit disappears, and the Lower Coal-measures rest directly upon the Carboniferous Limestone. At Haverfordwest this latter also vanishes, and inland from St. Bride's Bay the Coal-measures repose on Lower Silurian Rocks. These changes indicate the proximity of land towards the west during the Lower Carboniferous period.

Anthracite and Bituminous Coal-Districts.—It is well known that the coal-seams undergo a remarkable change in their extension from the east towards the west. While in the former direction they are bituminous, or gaseous, upon reaching the centre of the area, the same coal-seams become semi-bituminous, or "steam coals," and farther west, gradually pass into anthracite. Sir H. de la Beche states that this change takes place along a plane, dipping gently towards the S.S.E.; so that in the same spot, while the coals at the base of a hill may be anthracitic, those which outcrop along the heights above may be bituminous. Nor is this alteration in the character of the coals accompanied by outbursts of igneous rock, or by violent crumplings and contortions of the beds, as is the case in the Alleghany Mountains of America, where a similar change has been produced; on the contrary, the strata are usually but slightly thrown out of the horizontal position, except along the tract lying along the Gwen Draethfawr to the north of Mynydd Sulen, where the beds are considerably bent and folded. Other causes must therefore be sought for.

To the agency of a high internal temperature we must doubtless refer this change in the con-

stitution of the coal-seams. Wherever experiments or observations have been made, it has been found that the temperature increases with the depth; and in the case of the South Wales basin, some of the seams have originally been covered by ten or twelve thousand feet of strata, and their temperature in consequence raised above that of boiling water. Under such circumstances, the gases, we may suppose, would be slowly liberated from the coal-seams, and anthracite would be the result. But how are we to account for this metamorphic action taking place over one portion of the coal-field, and not over the other? This is, indeed, a problem difficult to solve, since the conditions in either portion do not seem to have been materially different. We may offer conjectural solutions of it, such as the greater increase of temperature over the western, or anthracitic, region, as compared with that over the eastern. This is the view advocated by Mr. E. T. Hardman, who supposes that the western extremity of the coal-tract has been subjected to a deep-seated and high temperature, due to the intrusion of masses of molten rock, and he points to the granitic and trappean rocks in the neighbourhood of Rosemarket, and the northern arm

of Milford Haven, of later date (according to the views of Sir H. T. De la Beche) than the Carboniferous rocks, as evidences of such igneous action.*

Pembrokeshire.—The western limit of the coal-field, containing only anthracite coal, has been subjected to considerable terrestrial disturbance, being much flexured and faulted. The general structure, along a line drawn from north to south, is represented in the following section, Fig. 5, from a drawing by Prof. Prestwich.†

Fig. 5.—SECTION ACROSS THE PEMBROKESHIRE COAL-FIELD.
Eight Miles.

m. Coal-measures.
n. Carboniferous Limestone.
o. Old Red Sandstone.

General Succession of the Coal-series in Glamorganshire and Monmouthshire.

Upper Pellengare Series, more than 3,400 *feet.*	1. Sandstones and shales down to the Mynydd Isslwyn coal. 2. Strata, with twenty-six coal-seams down to the Hughes vein; nine seams over two feet in thickness.

* "On the Origin of Anthracite." Journ. Roy. Geol. Soc., Ireland, vol. iv., p. 203.

† Mr. Prestwich has instituted a just comparison between

Pennant Grit Series, 3,246 feet (Swansea).	Hard and thick-bedding sandstones, etc., with fifteen coal-seams; five over two feet in thickness.
Lower Coal Measures, 450 to 850 feet.	Principally shales, rich in ironstones and coal-seams, of which there are thirty-four in all, and eight above two feet in thickness.
Millstone Grit.	Represented in the south by the Gower series.

It will be observed from the above general summary, taken from the Memoir of Sir H. T. De la Beche,* that the richest coal-bearing strata lie at the top and bottom of the formation; the central portion, formed of the Pennant Sandstone, being comparatively impoverished.

Lower Coal-measures.—These beds along the southern borders of the field form a well-marked zone, very rich in coal and ironstone, and distinguished by a remarkable group of fossil shells of marine genera; some of the species—as is also the case in the lower measures of the north of England—having survived from the period of the Carboniferous Limestone. It is a very remarkable fact that these lower measures appear to form the upper limit of an essentially marine fauna,

the flexures of the Pembrokeshire coal-field, and those of the Somersetshire coal-field along the base of the Mendip Hills, with the flexures of the Franco-Belgian coal-trough. Similar views were previously enunciated by Mr. R. Godwin-Austen.

* Memoirs of Geological Survey, vol. i.

the shells which occur in the higher beds being usually confined to the genus *Anthracosia* and its allies; and whatever may have been the conditions under which this genus of molluscs lived—whether (as once supposed) in fresh water, or in brackish,—the extent of its range, as compared with the Goniatites, Nautili, Pectens, Spirifers, and other shells of the Lower Coal-measures, seems to point to some marked physical difference between the original state of the middle and lower portions of the coal-formation.

The fossils of the Lower Coal-measures are found principally in the ironstones. The coal-seams occur in greatest number and thickness along the southern outcrop, where the series attains a thickness of nearly 1,000 feet.

Pennant Grit Series.—The Lower measures are surmounted by a great series of sandstones, introduced by the "Cockshoot rock," and included under the general term "Pennant Grit," the same by which this series is designated in Somersetshire. These sandstones form a fine range of escarpments, often reaching 1,000 feet in elevation; and within these escarpments is enclosed the great central table-land of Glamorganshire, composed of the higher strata of the Coal-formation. Along the deep valleys by

which this region is intersected, the coal-beds often crop out, and are worked by tunnelling into the heart of the hills. The whole series of strata, from the uppermost Pellengare beds down to the Millstone Grit, is from 10,000 to 12,000 feet in thickness, containing about eighty seams of coal, of which twenty-five are from two feet upwards, with an aggregate thickness of eighty-four feet of workable coal.* This great series is only surpassed in vertical development by that of Nova Scotia and Saarbrück in Rhenish Prussia; and it should be recollected that, as there is no certainty that the original uppermost beds of the Coal-measures are amongst those now existing on the central table-land, we are in ignorance of the actual thickness of the formation as originally deposited.

The following is a complete series of the coal-seams, with their corresponding names or designations, along the north and south outcrop, and their ascertained thicknesses, either individually or in groups. The series commences with the lowest bed, which has, in consequence, the largest area, and terminates with the uppermost.†

* The combined thickness of all the coal-seams, small and great, is stated by Professor Phillips to reach 120 feet.

† This Table is copied from Mr. Vivian's Report, drawn up for the Coal-Commission, vol. i.

Coal-Seams of the South Wales Basin.

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.*			Distinguishing the respective Crops of the Veins, with their various Thicknesses.		
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft.	in.
Crowsfoot vein. (Bottom seam.)	Crowsfoot vein. (Bottom seam.)	Crowsfoot vein.	North crop - - -	1	6
			South crop (north of anticlinal) - - -	2	0
			South of anticlinal -	2	0
			Doubtful, and under the sea - - -	2	0
			Plan No. 1 - -	—	
Pimp Quart vein. Fach vein. Rhasfach vein.	Rider. Four and Five Feet vein. Coal.	Five Quarters vein. Cribbwr Fawr vein. Cribbwr Fach vein.	North crop - - -	6	6
			South crop (north of anticlinal) - - -	10	2
			South of anticlinal -	13	7
			Doubtful, and under the sea - - -	10	2
			Plan No. 2 - -	—	
Hwch vein. Stenllyd vein. Grasuchaf vein. Grasissaf vein. Bresllwyd vein. Gwendraeth vein. Triquart vein.	Four Feet vein. Balance Pit vein. Tusker vein. Clay vein. Big vein (in Wem level.)	Three Feet vein. Six Feet vein. Rider. Smoke vein. Rider. Rider. Nine Feet vein. Danllyd vein.	North crop - - -	20	5
			South crop (north of anticlina) - - -	12	6
			South of anticlinal -	30	7
			Doubtful, and under the sea - - -	12	6
			Plan No. 3 - -	—	
White vein. Black vein. Little vein. Harnlo vein.	Coal and Mine vein. Five Feet vein.	Three Feet rider. South Fawr vein. Clay vein. Four Feet vein. Rider.	North crop - - -	14	0
			South crop (north of anticlinal) - - -	8	2
			South of anticlinal -	21	11
			Doubtful, and under the sea - - -	8	2
			Plan No. 4 - -	—	
Black Mine vein. Soap vein. Coal. Penstwryn vein.	Finery vein. Sulphury vein. Four Feet vein. Truro vein. Rider. Clay vein.	North Fawr vein. Three Feet vein.	North crop - - -	8	6
			South crop (north of anticlinal) - -	22	11
			South of anticlinal -	11	4
			Doubtful, and under the sea - -	22	11
			Plan No. 5 -	—	

* The plans are those referred to in the Report.

Coal-Seams of the South Wales Basin (continued).

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.			Distinguishing the respective Crops of the Veins, with their various Thicknesses.		
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft.	in.
Coal. ,, ,, ,, Fforch-y-Garen vein.	Coal. Cockshut rider. Silver vein. Balling vein.	Bwdwr Fach vein. Bwdwr Fawr vein. Sooty vein. Coal.	North crop - - -	9	9
			South crop (north of anticlinal) - - -	5	3
			South of anticlinal -	21	5
			Doubtful, and under the sea - - -	5	3
			Plan No. 6 - -	—	
Nil.	Black vein. Coal. ,, ,, Golden vein. Cockshut vein. Coal.	Bridge vein. Lantern vein.	North crop - - -	—	
			South crop (north of anticlinal) - - -	14	10
			South of anticlinal -	8	6
			Doubtful, and under the sea - - -	14	10
			Plan No. 7 - -	—	
Nil.	Cwmbyr vein. Cwmmawr vein.	Small vein.	North crop - - -	—	
			South crop (north of anticlinal) - - -	3	11
			South of anticlinal -	1	6
			Doubtful, and under the sea - - -	3	11
			Plan No. 8 - -	—	
Coal ,, ,, Llyngola vein.	Tormynydd vein. Jonah vein. White vein. Rider. Clay vein.	Double vein.	North crop - - -	9	2
			South crop (north of anticlinal) - - -	12	3
			South of anticlinal -	3	0
			Doubtful, and under the sea - - -	12	3
			Plan No. 9 . -	—	
Coal. ,, ,, Goch vein. Goch vein. Goch vein.	Field vein. Werndû vein. Werndû rider. Wernpistill rider. Wernpistill vein. Benson's vein.	Matthouse vein. Rock Fach vein. Rock Fawr vein.	North crop - - -	14	10
			South crop (north of anticlinal) - - -	13	7
			South of anticlinal -	9	4
			Doubtful, and under the sea - - -	13	7
			Plan No. 10 - -	—	

Coal-Seams of the South Wales Basin (continued).

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.			Distinguishing the respective Crops of the Veins, with their various Thicknesses.		
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft.	in.
Coal. Stinking vein.	Wythien Drewllyd. Penrhys vein. Pwll Robin vein. Coal. ,, ,,	Coal. Cilddoidy vein.	North crop - - - - South crop (north of anticlinal) - - - South of anticlinal - Doubtful, and under the sea - - - Plan No. 11 - -	3 9 7 9 —	6 0 2 0
Coal. William's vein.	Cistern vein. Sulphur vein. Rotten vein. Hughes vein.	Bettws Fach vein. Bettws Fawr vein.	North crop - - - South crop (north of anticlinal) - - - South of anticlinal - Doubtful, and under the sea - - - Plan No. 12 - -	3 13 14 13 —	6 8 1 8
Coal. ,, Tresgyrch.	Shenkin vein. Six Feet vein. Three Feet vein. Two Feet vein.	Nil.	North crop - - - South crop (north of anticlinal) - - - South of anticlinal - Doubtful, and under the sea - - - Plan No. 13 - -	7 12 — 12 —	8 1 1
Coal.	Five Feet vein.	Nil.	North crop - - - South crop (north of anticlinal) - - - South of anticlinal - Doubtful, and under the sea - - - Plan No 14 - -	4 4 — 4 —	0 9 9
Carnarvon vein. Carnarvon New vein. Penbryn vein. Coal. Coal.	Carnarvon vein. Carnarvon New vein. Penbryn vein. Four Feet vein. Two Feet vein.	Nil.	North crop, 9,860 acres - Ditto - - - - - South crop (north of anticlinal), 8,156 acres Ditto - - - - - South of anticlinal - Doubtful, and under the sea - - - Plan No. 15 - -	8 5 8 5 — 5 —	0 3 0 8 8

Coal-Seams of the South Wales Basin (continued).

Name in ascending Order of each Seam or Vein of Coal, One Foot and upwards in Thickness, contained in each Plan.			Distinguishing the respective Crops of the Veins, with their various Thicknesses.	
North Crop.	South Crop, North of Anticlinal.	South of Anticlinal.	Crops.	ft. in.
Rosy vein. Fiery vein. Golden vein. Bushy vein.	Rosy vein. Fiery vein. Golden vein. Bushy vein.	Nil.	North Crop - - - South crop (north of anticlinal) - - - South of anticlinal - Doubtful, and under the sea - - - Plan No. 16 - -	9 0 9 0 — — —
Coal. ,, ,, ,,	Penscallen vein. Little vein. Broad Oak vein. Glyngwernen vein.	Nil.	North crop - - - South crop (north of anticlinal - - - South of anticlinal - Doubtful, and under the sea - - - Plan No. 17 - -	13 8 13 8 — — —
Upper vein. Wythien Ffraith. Wythien Spagog. Gelly vein, or Wythien Drewllyd.	Upper vein. Wythien Ffraith. Wythien Spagog. Gelly vein, or Wythien Drewllyd.	Nil.	North crop - - South crop (north of anticlinal) - - - South of anticlinal - Doubtful, and under the sea - - - Plan No. 18 - -	11 0 11 0 — — —

Ironstones.—The Lower measures are the chief repositories of ironstone, as at Merthyr Tydvil, and at Taffe Vale, near Cardiff. They are seldom more than five inches in thickness, and frequently contain marine shells, fish, and plants. The following is an analysis of the principal bands, made at the Museum of Practical Geology :—

Analysis of Ironstones.

	Carb. Iron.	Earthy Matter.	Metal.
Upper vein, Ystradgynlas	86·0	14·0	41·5
Another vein, do. .	72·4	27·6	34·9
Cwm Phil vein . .	75·4	24·6	36·4
Pendaren Red vein . .	75·4	24·6	36·4
,, Jack vein . .	55·5	44·5	26·6
Black-band, Pontypool .	79·5	20·5	38·4

The yield of these Coal-measure ores, even in conjunction with the hæmatite from the Carboniferous Limestone, is sometimes not sufficient to supply the enormous consumption, and large quantities are imported from Northamptonshire, Oxfordshire, and other districts. In 1878 there were, in the anthracite district, 4 furnaces in blast, and in the bituminous district, 56 furnaces, producing in all 741,136 tons of iron.

Faults.—The fractures which traverse the South Wales coal-field are, in the great majority of cases, referable to one system, nearly perpendicular to the longitudinal axis of the basin, and therefore ranging from N.N.W. to S.S.E. A very few range from east to west. The remarkable parallelism of these fractures, and their direction with reference to the general arrangement of the strata, leave no doubt that they have all resulted from one system of disturbing forces.

Fossils.

The ironstones and shales of the Upper and Middle Coal-measures contain, as already stated, shells chiefly of the genus *Anthracosia;* but when we descend into the lower strata which overlie the Millstone Grit, we find a series of mollusca, closely resembling, and sometimes identical with, those of the Lower Coal-measures or "Gannister Beds" of the north of England. They are contained generally in the ironstone bands, and were determined by the late Mr. Salter from the collection of Dr. Bevan.*

1. Top.—Black-band ironstone. Fish: *Rhizodus*, *Megalichthys*. Shells: *Modiola*.
2. *Soap Vein.*—Tracks of *Annelids*, and a new genus of bivalve shells peculiar to the Coal-measures.—*Anthracomya*.†
3. Ironstone above "3-quarters Coal."—*Anthracomya*.
4. Ironstone over Bydyllog Coal.—*Athyris planosulcata:* a shell also found in the Carboniferous Limestone.
5. Darin Pins Ironstone.—*Anthracosia*, *Anthracomya*, *Myalina* (same species as in the "Pennystone" band of Coalbrook Dale). *Avicula* (?).
6. Ironstone over "Engine Coal."—*Spirifer* and *Productus*.
7. "Old Coal" black band.—*Anthracosia acuta*, and *A. ovalis*, both common species in the Coal-measures.

* For description and figures of many of these fossils, see "Iron Ores of Great Britain," Part iii.

† Genus established by Mr. Salter. "Iron Ores of Great Britain," Part iii., p. 229.

8. Spotted Vein.—Tracks of *Limulus*, a crustacean allied to the King Crab—and *Spirorbis carbonarius*.
9. Bottom Vein.—Fish: *Megalichthys*, *Rhizodus*, *Palæoniscus*, *Amblipterus*, *Pleurocanthus*, *Helodus*, *Pecilodus*, *Pleurodus*.
10. Bottom Rosser Vein.—Fossils of the Carboniferous Limestone. *Spirifer bisulcatus*, *Orthis resupinata*, *O. Michelini*, *Chonetes Hardrensis*, *Streptorhynchus crenistria*. *Productus semi-reticulatus*, *Edmondia Unioniformis*. *Axinus Carbonarius*. *Productus Cora*, *Conularia quadrisulcata*, *Nautilus falcatus*.

Entomostraca.—In certain black-band ironstone strata, lying about thirty yards above the "Rider Coal," in the Pennant series, Mr. W. Adams, of Cardiff, in 1869, discovered some very interesting forms of Entomostraca, figured and described by Professor Rupert Jones, and associated with *Anthracomya Phillipsii*. Some of the species are new, and include the genera *Estheria*, *Carbonia*, and *Leaia*.*

Resources.

The estimates which I originally gave of the resources of this coal-basin down to a depth of 4,000 feet, amounted to 24,000,000,000 tons; of which I considered 16,000,000,000 available for future use. For these estimates I now substitute those of Mr. H. H. Vivian and Mr. G. T. Clark,†

* Geol. Mag., vol. iii., p. 214 (1870).

† Rep. Coal Commission, vol. i.

with slight modifications. First, I deduct from their estimate of the available quantity down to 4,000 feet of depth (viz., 32,456,200,913 tons) the quantity worked since 1870—viz. (in round numbers), 150,000,000 tons; and second, the quantity below 2,000 feet credited to the thin seam called the "Crow's-foot," which lies at the bottom of the whole series, amounting to about 140,000,000 tons.* This will leave as the net available quantity, 32,166,200,913 tons.

Estimate of the Mineral Resources of the South Wales Coal-Basin (including Monmouthshire).

1. Superficial area of the Basin .	906 square miles.
2. Greatest thickness of Coal-measures	12,000 feet.
3. Number of Coal-seams of 2 feet and upwards 25, giving a thickness of about	84 feet of workable coal.
4. Total quantity of coal in 1870 down to 4,000 feet of depth (about) .	32,456 millions of tons.
5. Quantity available for future use after making deductions as above stated (about)	32,166 millions of tons.

The quantity of coal raised in 1878 in this coal-basin was 17,416,515 tons from 662 collieries. At this rate of production the supply is sufficient to last for about one thousand eight hundred years.

* I am not sufficiently courageous to believe that a seam of coal of an average thickness under 2 feet will ever be worked at a greater depth than 2,000 feet, if so much.

CHAPTER II.

BRISTOL AND SOMERSETSHIRE COAL-FIELD.

At an unusually short distance from the base of that range of Oolitic escarpments which stretches in a deeply indented line from Gloucestershire to Dorsetshire, lies the Bristol coal-field.* The thick series of formations which in the midland counties intervenes between the Coal-measures and the Lias, are here, either greatly reduced in thickness, or altogether absent; and hence we may pass from the one formation to the other within a distance of a hundred yards.†

The coal district is divided into two principal basins; the northern situated chiefly in Gloucestershire, and the southern chiefly in Somersetshire. This latter is by far the larger.

* It ought to be stated that as early as 1730, Mr. Strachey described the coal-districts of Somersetshire in a series of communications to the Royal Society, and from his sections it is evident he understood the relative positions of the Oolite, Lias, and Red Marl, to the Coal-measures, and limestone of the Mendips.

† This district is illustrated by the Geological Survey Maps, 19, 35, and Sections, sheets 14, 15.

These basins are separated from each other by a broken, or faulted, anticlinal, ranging in an east-and-west direction, and crossing the River Frome about two miles north of Bristol. By this fault the "Pennant" Sandstone of the northern basin is brought into contact with the lower measures which underlie that formation on the south side of the fault; there is thus a "downthrow," or relative lowering of the beds along the north side, as shown by the small map. The occurrence of the Pennant to the north of the fault has greatly retarded the development of the lower seams which have been largely worked on the southern side of the anticlinal.

At Cromhall the coal-field terminates in an apex, from which it gradually expands in a southerly direction, till, east of Bristol, it reaches a width of seven miles. Along, and beyond, the edge of the basin the beds rise at high angles. The Millstone Grit and Carboniferous Limestone form parallel belts, which range from the Mendip Hills to Tytherington and Cromhall. Upon the upturned edges of these more ancient formations the New Red Marl and Lias rest almost horizontally (*see* Section, Fig 6, p. 111). South of Bristol, the

boundary of the coal-field, marked by the range of limestone hills, sweeps round to the westward, and is lost under the sea beyond Nailsea Moor, near Clevedon, in Somersetshire. South of this the Coal-measures underlie the Liassic formations of Dundry Hill, and encircle the large mass of Carboniferous Limestone near Congresbury. Over the greater part of this area the coal-formation is buried at moderate depths under newer horizontal strata.

Along the southern boundary of the coal-field the Carboniferous Limestone of the Mendip Hills rises to the surface, trending from west to east, till lost beneath the Lias and Oolite, W. of Frome. I am assured, however, by Mr. Etheridge, that the basin-shaped structure of the Carboniferous Rocks under the Lias and Oolite has been thoroughly established by actual sinkings and borings through these newer formations,

Fig. 6.—SECTION ACROSS THE BRISTOL COAL-FIELD.

A. Old Red Sandstone.
B. Carboniferous Limestone.
C. Millstone Grit.
D. Coal-Measures, with coal.
5. Lower Oolite.
4, 3, 2. Upper, Middle, and Lower Lias.
1. New Red Marl (Trias).

so that the lowermost coal-shales, or Holcombe Series, do not pass eastward of a line joining Bath and Frome. On reaching Mells, the lowest beds bend round to the North, and take a course through Buckland, Norton St. Philip, Midford, Twiverton (where coal is worked), and North Stoke. It will be observed that this outcrop is in the line of the great N.—S. dislocation, which passes by Chipping Sodbury and Cleeve Bridge, near Doniton.*

The extreme length of this coal-field, from its northern apex at Cromhall to the flanks of the Mendip Hills, is twenty-six miles; the general strike of the beds north of the valley of the Avon being north and south, and over the area south of this line from west to east. About one-half of the northern basin is overlaid by nearly horizontal strata of the Triassic and Oolitic periods, and of the southern part nine-tenths are covered over in this manner; yet the existence of the underlying coal-field is

* I was formerly of opinion, with many others, that the coal-field stretched eastwards from the Mendip Hills under the Oolites, by Bath, Bradford, and Frome, until informed to the contrary by Mr. Etheridge, who is well acquainted with the trials which have been made to prove coal in this direction. It is very probable, however, that the Coal-measures roll in again under the Cretaceous rocks of the Vale of Wardour.

abundantly proved, not only from theoretical considerations, but by actual sinkings for coal. Shafts penetrating the Lias and Red Marl into the coal have been sunk at Paulton and Timsbury; and another near Radstock, commencing in the upper beds of the Lias, reaches coal at 200 fathoms.*

The succession of strata in the neighbourhood of Bristol has been determined by Mr. D. Williams,† and is as follows:—

Succession of Strata near Bristol.

Lias . .	Lower, Middle, and Upper Lias.	
Trias (keuper)	Red Marl.	
	Dolomitic conglomerate.	
Coal-Measures	Upper series, with 22 coal-seams, of which 9 average two feet and upwards in thickness . .	3,000 ft.
	Central or Pennant Sandstone, etc., 5 coal-seams	1,725 ft.
	Lower shales, 36 coal-seams. .	2,000 ,,
Millstone Grit	Hard siliceous grits, etc. . .	950 ,,
Carboniferous Limestone		2,338 ,,

There is thus a total thickness of strata with coal of 6,725 feet, separated into two divisions by a series of hard, flaggy sandstones (Pennant),

* "Lectures on Geology," by Mr. R. Etheridge, 1859. A little book containing much valuable information about the Bristol coal-field; and to its author I am indebted for many details concerning this district.

† Mem. Geol. Survey, vol. i., p. 207.

which will prove a serious obstacle to sinking in search of the lower coals. Of the 63 coal-seams above mentioned only 20 are 2 feet and upwards in thickness, producing 71 feet of coal.*

The Coal-measures have been arranged by Mr. Etheridge under the following subdivisions: †

Upper . .	Radstock series. Farrington series.
Middle . .	The Pennant series.
Lower . .	Bedminster series. Aston, or Holcombe series.

The Radstock series (see section below) occupies a small area in the southern part of the coal-field between Kilmersdon and Farmborough.

The Farrington series forms a much larger area—from Holcombe on the south, to near Brislington on the north, and from Combe Hay on the east, to Chew Magna on the west.

The Bedminster series encircles the last in a band about one mile and a half broad along the east, and on the west occupies the greater part of the flat ground around the limestone inlier

* Prof. Prestwich, F.R.S., who, as one of the Commissioners, has drawn up an able Report on this coal-field, gives the number of seams as 46 with 98 feet of coal. The numbers and thicknesses of the seams depend of course very much on the part of the district where the section is taken. I have adopted Mr. Prestwich's estimates of thickness of the upper and lower coal-series.

† "Lectures on Geology."

of Congresbury and Backwell, stretching to the sea-coast under Nailsea Moor, Kenn Moor, Nempnet, and Puxton. It also forms a greater part of the Northern district.

The lowest series of Holcombe forms a narrow belt lying immediately over Millstone Grit or "Farewell Rock." Along the edge of the Mendips, and at Twiverton, the strata are highly disturbed and dislocated. The seams of the lower series decrease in number and importance, both southward at Nailsea, where they are reduced to twelve, and northward to Yate and Cromhall, where only seven seams exist. They attain their fullest development in the central area.*

According to Mr. Walter Saise, the Upper measures furnish chiefly gas and house coals, the Middle or Pennant beds are noted for smiths' coal and good fire-clay, and the Lower for steam coal and associated ironstone.†

The following is the general succession of the Coal-series, for which I am indebted to Mr. Etheridge, and which is very similar to that published by the Geological Survey:—

* Mr. Prestwich, "Report," p. 39.

† "Notes on the Bristol Coal-field," read before the Geological Section of the British Association at Bristol, 1875.

General Coal-series of the Somersetshire Coal-field.

NORTH SIDE.

	Name of Coal-seam, etc.	Ft.	In.
	New Red Sandstone and Marl at Coal Pit Heath	270	0
	Radstock Series.		
	(Not represented in the Northern district.)		
Farrington Series.	*Coal*	1	4
	Shale and rock, with thin seams	102	0
	Hard Seam	3	0
	Shale with coal, 1 ft.	123	0
	Hollybush Coal	3	0
	Shales and Sandstone	52	0
	Great Seam (in three beds)	5	0
	Strata, etc.	238	0
	Coal	1	6
	Strata	215	0
*Pennant Series.**	Hard sandstone, with a few beds of shale—and three coal-seams, each about two feet in thickness	1500	0

SOUTH SIDE.

	Name of Coal-seam, etc.	Ft.	In.
	New Red Sandstone and Marl	120	0
	Dolomitic conglomerate ("millstone")	6	0
	Sandstone and shales	240	0
	Withey Mill seam	1	0
	Strata		
	Great seam of Clair Down	2	0
	Strata, with two thin seams	67	6
	Middle seam	1	8
	Strata	100	0
	Silven vein	2	6
	Strata	40	0
	Little seam	1	6
	Strata (*with Bull seam, etc.*)		
Farrington Series.	*Sulphurous coal*	2	0
	Strata	36	0
	Cat-head seam	2	0
	Strata	36	0
	Three-seam coal	3	0
	Shales, etc., with *Anthracosia*	54	0
	Peacock coal	2	0
	Shales	36	0
	Shaley seam	2	0
	Shales	36	0
*Pennant Series.**	Principally hard sandstones, with 5 seams of coal.	1500	0

* Mr. Prestwich states that the Pennant rock has been traversed to a depth of 800 feet, and has probably a mean thickness of not less than 2,000 feet. The following are the seams which it contains. In the Nettlebridge district, the "Globe seam," 3 feet thick, of good quality. In the Bristol district, the "pig seam," 10 inches; the "Millgrit seam," 3 feet to 6 feet, a smith and steam coal; the "rag seam," from 1 to 4 feet; the "devil's seam," 2 feet to 4 feet, of uncertain quality.—REPORT, 37.

General Coal-series of the Somersetshire Coal-field.

(*Continued.*)

NORTH SIDE.				SOUTH SIDE.			
	Name of Coal-seam, etc.	Ft.	In.		Name of Coal-seam, etc.	Ft.	In.
Bedminster Series.	*Cock-seam*	2	0	*Bedminster Series.*	*Small Coal*	3	0
	Sandstone	42	0				
	Hen-seam	1	6		*Dead Course*, or		
	Strata	180	0		shell-seam	3	0
	Coal	2	6				
	Strata	540	0		*Garden Course*	3	6
	Britton's seam	1	2				
	Strata	300	0		*Strap-seam*	2	6
	Coal	3	0				
	Strata	78	0		*Great Course*	4	0
	Shelly Vein Coal	3	0				
	Strata	54	0		*Firestone-seam*	3	0
Holcombe Series.	*Hard-seam*	1	7	*Holcombe Series.*			
	Sandstone and shale	360	0		*Dungy Drift*	2	0
	Coal	4	0		*Hard Coal Drift*	3	0
	Strata	60	0		*Perkin's Course*	2	0
	Great-seam	4	0		*Foot-coal*	2	0
	Sandstone	60	0		*Branch-coal*	4	0
	Coal		6		*Golden Candlestick*	2	6
	Shale	120	0		*North Sheets*	4	0
	Coal	2	0		*Cat* (red ash)	1	0
	Shale	48	0		*South Sheets*	3	0
	Slate-seam	1	8		*Riband-coal*	1	2
	Shale	24	0		*Standing-coal*	4	0
	Coal	1	0		*Fern Rag*	2	6
	Strata	24	0		*Stone Rag*	3	0
	Coal	1	0		*Callow's-seam*	4	0
	Sandstone	60	0		*Penrick*, or *Black-*		
	Stoney-seam	1	4		*stone-coal*	3	0
	Strata	180	0		*White-axen* (ash)	2	6
	Coal	4	0		*Firestone-seam*	2	0
	Millstone Grit	180	0		Millstone Grit		

NOTE.—The *terms* used at the sides of the columns are intended to show that the seams, in the North and South area of the Coal-field, are most likely the same under different names, and are here attempted to be correlated.

Flexures and Faults.—The Coal-field is divided into two principal parts by an anticlinal axis, which runs east and west through Kingswood, where it brings the coals of the lower series to the surface, and throws off the Pennant rocks on its flanks. The axis itself is parallel to a large fault already described (page 110), and is traversed by a number of faults, mostly of uncertain value, by which the workings of the coal-seams are interrupted.

Another great disturbance is one which places the Coal-measures in a vertical position along the northern base of the Mendip Hills, the axis of which is parallel to the former, and ranges east and west. Along this line the Coal-measures are tilted vertically, and have in some cases a reversed dip, so that the coals can often be worked to a depth of 200 or 300 feet perpendicularly, the shaft following the course of the seam. The coal, especially when the dip is reversed, is generally much broken, and often so mixed with shale and stone as to be useless. In connexion with this latter disturbance is the remarkable "slide fault," by which the upper portion of the Radstock series has been thrust almost horizontally for a distance of 130 to 220 feet northward over the

lower portion.* To the south of Chelwood the beds are broken by several faults.

Outlying Basins.—Two outlying basins, situated to the north and south of the mouth of the Avon, have been proved to exist. One of these, partially submerged beneath the River Severn, has been discovered by borings, and the railway excavations at Almondsbury,† and the other occurs at Nailsea, lying in an oval hollow surrounded by Millstone Grit and Carboniferous Limestone, where coal has been worked. Only the lower seams, reduced to twelve in number, are found in this latter basin, and they are partially concealed by the Red Marl formation. The positions of these basins are shown on the map (Plate II.)

Fossils.—But few animal remains have been found in this coal-field, but bivalve molluscs (*Anthracoptera* and *Anthracosia?*) have been recorded from Tiverton and Camerton by Professor Morris—and remains of *Entomostraca* (*Estheria striata*, *Beyrichia arcuata?*) from Nailsea, determined by Prof. T. R. Jones. Two

* Mr. Prestwich, Report, vol. i., p. 60.

† These are described by Mr. Prestwich (*ibid.*, p. 164), who quotes Report of Mr. C. Richardson, C.E. to Bristol Chamber of Commerce.

specimens of Limulus have also been found by Mr. E. Feare.*

Resources.

In attempting to estimate the future resources of this coal-field, great deductions are unquestionably necessary from the calculated quantity of coal, owing both to general and special circumstances. Besides excluding all seams below 4,000 feet in depth, we must, I think, omit many of those within this depth, owing to thinness and deterioration in quality. The Pennant rock, which overspreads so large a portion of the lower series of coals, will also undoubtedly prove a serious obstacle, owing to the expense of sinking through it; while the contorted and crushed state of the coals along the southern borders of the field is likely to discourage working at great depths in that district.

Professor Prestwich, who, with the assistance of Mr. Anstie, has made an elaborate series of estimates for each parish, giving a grand total of nearly 7,000 millions of tons, has rightly appreciated the force of those special difficulties likely to attend future mining operations, and has made considerable deductions in conse-

* Geol. Mag., vol. v., pp. 356-7.

quence.* Still, I cannot but regard the quantity remaining as in excess of that which may reasonably be calculated upon, owing to the thinness, for the most part, of the seams of coal themselves; as those which are now worked at moderate depths may be quite unworkable when the depth reaches, or exceeds, 1,000 yards. Having premised so much, I shall put the reader in possession of Professor Prestwich's and my own estimates.

The Author's Estimate of Resources.

1. Area (of which only 45 square miles are not concealed by newer formations)	150 square miles.		
2. Greatest thickness of measures with coal	5,125 feet.		
3. Number of coal-seams from 2 feet and upwards, 20, giving a thickness of coal of	71 ,,		
4. Total original quantity of coal (corrected for denudation) . .	4,148 millions of tons.		
5. Deduct for quantity inaccessible, spoiled, etc., one-third, leaving .	2,766	,,	,,
6. Deduct for quantity already worked out, one-tenth, leaving . .	2,489	,,	,,
7. Deduct for quantity below the depth of 4,000 feet, one-fifth; leaving for future supply (about) . .	2,000	,,	,,

* Equal to one-fifth on the quantity in the lower series, after necessary deductions of the usual kind.

*Professor Prestwich's Estimate.**

		TONS.
1.	Quantity of coal at a less depth than 1,500 ft.	1,718,791,280
2.	,, ,, between 1,500 and 3,000 ,,	1,519,997,981
3.	,, ,, between 3,000 and 6,000 ,,	2,227,531,577
4.	,, ,, between 6,000 and 8,000 ,,	637,990,144
		6,104,310,982

Or, excluding the quantity below 4,000 feet, and deducting the quantity worked since 1870, there remain 4,210,000,000 tons for future use.

The annual output of coal from this coal-field is about 1,000,000 tons from sixty-one collieries.†

On the Prospects of Coal South of the Mendip Hills.

Along their southern margin, the Carboniferous Limestone which forms the main mass of the Mendip Hills dips to the southward, through a tract of country ranging from Worminster and Westbury to Pleadon. The district to the south —forming the valley of the river Brue—is overspread by alluvial and Mesozoic strata, consisting of Lias and New Red Marl, through which some abortive attempts have been made to reach coal

* Report, vol. i., p. 50.

† Mr. R. Hunt, "Mineral Statistics" (1878).

beds.* The Carboniferous Limestone of Cannington Park may be considered to indicate the southern boundary of the possible basin. For many years past geologists have inferred the existence of a concealed coal-field ranging under the valley of the Brue westward into and beneath the Bristol Channel.† The rising up of the Mendip ridge, which is a broken arch, or anticlinal axis, bounded both to the north and south by similar low-lying tracts, covered by Mesozoic strata, induces us to infer similar geological conditions on either side. The presence of Coal-measures along the northern margin of the ridge we know to be a fact; and we, therefore, infer their presence beyond the southern margin. Assuming this to be the case, we have to recollect that (as Professor Prestwich observes) the Mesozoic rocks on the south of the Mendips are probably of greater thickness than they are to the north, and Sir R. Murchison has shown that the existence of the Culm-measures of Devonshire points to a rapid deterioration of the

* Described by Messrs. Bristow, F.R.S., and H. B. Woodward, Geol. Mag., Nov. 1871. Mr. Bristow records the presence of Millstone Grit at Priddy and Dinder.

† Prof. Ramsay, Mem. Geol. Survey, vol. i., p. 305; Prof. Prestwich, Report, vol. i., p. 163. Mr. Bristow, Op. Cit., p. 4.

Coal-measures in that direction. Probably as long as coal can be reached with such comparative ease in the Bristol district, that of the Brue valley will not be perseveringly essayed. Meanwhile it may be affirmed that the evidence is in favour of the supposition of a concealed coal basin containing seams of inferior quality.

CHAPTER III.

FOREST OF DEAN COAL-FIELD, GLOUCESTERSHIRE.

THE structure and resources of this little coal-field are now thoroughly understood. It forms a more perfect "basin" than any other coal-field in England; as the strata everywhere dip from the margin towards the centre, except at one part of the western side, where the oval outline is interrupted for a short distance.*

The Coal-measures are surrounded by belts of Millstone Grit and Carboniferous Limestone, which generally rise considerably above the tract of the Coal-measures they enclose, just as the banks of a lake are higher than the lake itself; and the Carboniferous Limestone in turn rests upon a bed of Old Red Sandstone.† The general

* The Royal Forest covers a space of 23,000 acres, of which 11,000 are in timber. Deer formerly abounded, but are now almost extinct.

† See Maps of the Geological Survey, 43, S.E. and S.W., and Mr. Sopwith's large Map in the Museum of Practical Geology.

structure resembles that of the South Wales coal-field in miniature.

Scenery.—The scenery around the skirts of this coal-basin is rich and varied. The eastern ridge of the Carboniferous Limestone overlooks the Vale of the Severn, and commands the escarpment of the Cotswold Hills of Gloucester and Somerset. At the opposite side of the coal-field the eye rests upon the Vans of Brecon, 2,700 feet in height, and the ranges which mark the northern bounds of the great South Wales coal-field. The limestone ridge on which you stand is cut into lofty cliffs lining the gorge of the Wye, and in its extension southwards towards Chepstow produces those remarkable terraces which render the scenery of that part of the river as beautiful as it is peculiar.

The area of the coal-field is about 34 square miles. It contains 15 seams of coal, of which only 8 are of a thickness of 2 feet and upwards; and the total series, as stated by Sir H. de la Beche, is as follows:*—

1. Coal-measures, with 15 coal-seams	2,765	feet.
2. Millstone Grit	455	,,
3. Carboniferous Limestone . .	480	,,
4. Lower Limestone Shale . .	165	,,
5. Old Red Sandstone . . .	8,000	,, or more.

* Mem. Geol. Survey, vol. i., p. 203.

In the Carboniferous group there is a decrease by two-thirds in the thickness of the strata as compared with the Bristol district. Over the centre of the basin the strata lie nearly horizontally. On approaching the eastern borders they rise very rapidly, but along the opposite, or western edge, the lower beds spread out considerably, and in consequence have a much larger horizontal range than those higher up in the series. The coals are being gradually worked from the margin of the basin, where they crop out, towards the centre, where they are deep; on which account it is probable that progressive mining operations will be much hindered by the accumulation of water in the old workings.

Succession of the Coal-seams.

	Ft.	In.
Sandstones and shales with thin coals .	830	0
Cow Delf	0	8
Strata	91	10
Dog Delf	1	2
Strata	46	9
Smith Coal	2	6
Strata	34	6
Little Delf	1	8
Strata	48	8
Park End High Delf	3	7
Strata	56	0
Starkey Delf (with parting)	2	0
Strata	50	0

		Ft.	In.
Rocky Delf		1	9
Strata		77	6
Upper Churchway Delf (with partings) .		1	11
Strata		34	0
Lower Churchway Delf		1	6
Strata		150	0
Braizley Delf		1	9
Strata		430	0
Nag's Head, or *Yorkley Delf* . . .		2	9
Strata		153	0
Whittington Delf		2	6
Strata		137	0
Coleford High Delf (variable) . .	2 to	5	0
Strata		124	0
Upper Trenchard Delf		2	0
Strata		72	0
Lower Trenchard, or *Bottom Coal* . .		1	4

Many of the coal-seams are exceedingly variable in thickness and quality, as I know by painful personal experience. The Coleford High Delf is subject to rapid fluctuations in thickness, and is so soft that only about 2 feet can be extracted as large coal, the rest being slack or small.

The Forest of Dean in 1878 contained 9 iron furnaces, of which 2 were in blast, producing upwards of 40,000 tons of pig-iron. The ore used is derived from the clay-ironstone of the Coal-measures, from brown hæmatite extracted from

the Carboniferous Limestone, and from other extraneous sources.*

The Horse.—In one of the coal-seams, called "Coleford High Delf," there occurs one of those interruptions in the regular course of the strata, which tend to throw much light on the original conditions under which coal was formed, but are an occasion of serious loss and disappointment to the proprietor. River channels filled with sand, traversing coal-seams, occur in almost every coal-field, and are known as "rock-faults" and "horse-backs;" but the case to which I have alluded is so remarkable, and has been so fully investigated, that it will serve as a general illustration of these phenomena in other districts.† The description is by Sir H. de la Beche,‡ who says:—The horse with its branches resembles a channel cut amongst a mass of vegetable matter in a soft condition. It ranges S. 31° E. for a length of two miles, and a breadth of 170 to 340 yards. A number of minor chan-

* The brown hæmatite accompanies the Carboniferous Limestone which nearly encircles the coal-field, and was worked by the Romans during their occupation of Britain. In 1869 there were extracted 172,023 tons.—Hunt, Min. Stat., p. 64.

† Mr. Jukes has very fully described these *horses* or *rock-faults* in the "Thick Coal" near Dudley, in his "Memoir on the South Staffordshire Coal-field," p. 45.

‡ Mem. Geol. Survey, vol. i., p. 156.

nels communicating with each other and the main channel are named "Lows." Mr. Buddle compares the *horse* to the bed of a river, and the *lows* to smaller streams cutting only a lesser depth. The channels are filled principally with sandstone, which extends over the coal-seam, and forms its roof.

Resources.

1. Area of coal-field	84 square miles.
2. Greatest thickness of Coal-measures	2,760 feet.
3. Number of coal-seams from 2 feet and upwards, 8, giving a total thickness of	24 ,,
4. Total original quantity of coal (corrected for denudation) . .	842 millions of tons.
5. Deduct for loss and quantity worked out, etc., leaving for future use	260 ,, ,,

CHAPTER IV.

COAL-FIELD OF THE FOREST OF WYRE, WORCESTERSHIRE.

A COAL-FIELD of about as large a superficial extent as that of the Forest of Dean stretches from the northern end of the Abberley Hills, and spreading out under the Forest of Wyre, ultimately becomes contracted northwards to a narrow band lining the banks of the Severn south of Bridgenorth.

The Coal-measures repose on a bed of "Old Red Sandstone,"* consisting of red marls, sandstones, and cornstones (concretionary earthy limestone), and are overlaid by a thick mass of Lower Permian strata, composed of red sandstones and marls with calcareous conglomerates, and marly breccia,† very fully developed at Enville. This

* Really as I believe "Estuarine Devonian." See Quart Journ. Geol. Soc., May 1880, p. 268.

† "Breccia" is a word used to designate strata formed of angular pebbles, "conglomerate" being confined to strata in which the pebbles are rounded or water-worn.

Permian breccia has excited much interest regarding its origin; for Professor Ramsay has shown that it bears a strong resemblance to accumulations originating in glaciers, and spread over the sea-bottom by floating ice; such as that of the Boulder clay of the Glacial epoch. If this theory be correct, a vast change must have come over the climate of these countries between the coal-period and that which immediately succeeded it.

This coal-field has not been fully explored; but, as far as is known, the coal-seams which it contains are both thin, and of inferior quality. The following series occurs near the western margin, as exhibited in Mr. Aveline's section drawn across this district.*

Section of Coal Strata, Forest of Wyre.

	Ft.	In.
1. Sandstone and shale	76	0
2. Coal	1	10
3. Sandstone and shale	24	0
4. Coal	2	0
5. Sandstone and shale	39	0
6. Coal	4	0
7. Sandstone, shale, etc.		

* Sections of the Geol. Survey, Sheet 50; also Geol. Map, 55, N.E.

*Section at Harcott Colliery, Clee Hill Common, Forest of Wyre.**

		Ft.	In.
1.	Coal-measures	157	0
2.	Blue Bind	6	0
3.	Coal	1	0
4.	Measures	26	0
5.	Black Shale	1	0
6.	Measures	100	0
7.	Coal	1	3
8.	Measures	12	0
9.	Black Parting	0	6
10.	Measures	5	0
11.	Sweet Coal	4	6
12.	Ironstone and Rock	3	0
13.	Coal	0	9
14.	Clod	0	6
15.	Coal	1	8
16.	Black Clod and large balls of Ironstone	5	0
17.	Coal	6	0
18.	Clod	2	6
19.	Coal	2	6

A coal-seam described as being "sound, bright, and semi-bituminous" has recently been reached at a depth of 305 yards at Highley.† This seam is known as "the Stanley Coal," and has a shale

* Extracted from a valuable paper by Mr. Daniel Jones, F.G.S., "On the co-relation of certain Carboniferous Deposits of Shropshire," in which he endeavours, not unsuccessfully, to explain the changes which have taken place in the beds from Coalbrook Dale, Harcott, Brown Clee, and Cornbrook.—Geol. Mag., vol. viii., p. 363 (1871).

† Mr. W. Molyneux, *Mining Journal*, Nov. 15th, 1879.

roof and fire-clay floor. Above it is the "main coal," 7 feet 6 inches in thickness, the bottom part, 4 feet thick, being of good quality. As these seams have a considerable horizontal range, the mineral prospects of this district seem to be of a fair character.

The strata of which this coal-field is composed represent chiefly the Upper Coal-measures, which seldom contain beds of coal of much value or thickness. One bed, however, varying from 4 to 5 feet, has been traced by the late Mr. G. E. Roberts over a considerable extent of the central part of the coal-field. The absence of the lower portion of the formation may be accounted for on the supposition that this part of England was dry land till near the close of the Carboniferous epoch.

Mr. Roberts has brought to light several very interesting particulars regarding the fossils, both animal and vegetable. In a band of limestone, apparently synchronous with that in the Upper Coal-measures of Coalbrook Dale, Warwickshire, and elsewhere, he has found fish-teeth and scales, *Leperditia inflata*, *Spirorbis carbonarius*, and fine specimens of *Posidonia*, determined by Professor Rupert Jones. But perhaps the most interesting palæontological objects obtained by

Mr. Roberts, are specimens of *Pecopteris* and other ferns, retaining their fructification.*

At Arley Colliery, near Bewdley, the strata have been penetrated to a depth of 454 yards, ultimately reaching a mass of basaltic rock. Only one workable coal, at a depth of 176 yards, appears to have been found.

* For further details see Mr. Roberts' "Rocks of Worcestershire."

CHAPTER V.

SHREWSBURY COAL-FIELD.

THIS coal-field forms a narrow band extending from the base of Haughmond Hill, east of Shrewsbury, to the banks of the Severn near Alberbury, a distance of about 18 miles. Like the coal-field of the Forest of Wyre, the coal-strata repose on the older rocks without the intervention of the Millstone Grit and Carboniferous Limestone; but in this instance the fundamental rocks belong to the Cambrian and Lower Silurian periods. Notwithstanding its length, it is seldom more than a mile in breadth; and in its lower part contains two or three coal-seams which have been worked to a small extent, but are not of sufficient value to induce mining operations far from the outcrop.

The Coal-measures are overlaid by Lower Permian strata, consisting of red and purple marls and sandstones, surmounted at Alberbury and Cardeston by a remarkable stratified

breccia,* composed of angular fragments of white quartz, and Carboniferous Limestone, cemented by calcareo-ferruginous paste. The "Alberbury breccia" may be regarded as the remnant of an old shingle beach formed round a coast-line, composed of Carboniferous and Silurian rocks.

In the upper part of this coal-field a band of limestone † occurs with estuarine and marine organisms, some of which were at first supposed to be of fresh-water origin. It contains a small crustacean, *Cythere*, a bivalve shell, *Anthracosia*, and an annelide, *Spirorbis carbonarius*. Now, it is a remarkable instance of the persistency of some calcareous strata over large areas, that this band of limestone, seldom more than a foot in thickness, can be traced in the Coal-measures of Coalbrook Dale and the Forest of Wyre southward, those of Lancashire northward, and of Warwickshire eastward, representing an area of about ten thousand square miles; and throughout this expanse it is always found associated with those uppermost coal-strata, which preceded the introduction of the Permian rocks.

* Sir R. I. Murchison, "Silurian System," p. 63.

† This limestone is described by Sir. R. I. Murchison ("Siluria," p. 321).

The coal-fields of the Forest of Wyre, the Clee Hills, and Shrewsbury, together with a fourth district extending from the base of Caer Caradoc to within a few miles south of Shrewsbury, are of so small a value in regard to their coal deposits, that I do not consider it necessary to attempt an estimate of their resources. They have all been formed in the vicinity of old land-surfaces, and around lines of coast composed of more ancient rocks. The strata themselves belong generally to the higher part of the coal-series, which throughout England is but sparingly enriched with beds of coal. Their relations to the Coal-measures of Coalbrook Dale have been carefully worked out by Mr. Daniel Jones.*

The Coal-fields of the Clee Hills, Salop.

Two small outlying coal-tracts, remnants of a formation which once spread continuously from South Wales and Gloucestershire, are perched on the summits of the Titterstone and Brown Clee Hills in Shropshire, at a height in the latter case of 1,780 feet above the sea, and if lighted up with the combustible materials with

* "On the co-relation of the Carboniferous Deposits of Cornbrook, Brown Clee, Harcott, and Coalbrook Dale."—Geol. Mag., vol. viii., p. 363 (Aug. 1871).

which they are stored, would serve as beacon-fires for many a mile around.

These coal-fields are rather more than a mile each in diameter, and are capped by a bed of hard basalt, to which, owing to its power of resistance to agents of denudation, the hills probably owe their preservation. On these flat-topped hills are planted several small collieries, whose shafts pierce the basalt before entering the coal. The vent from which this igneous rock has been erupted is situated in the Titterstone Clee Hill; and from this orifice the basalt has apparently been poured forth in the form of liquid submarine lava, at some period after the Coal-measures were formed.* The thickness of the coal formation is but small, containing only two or three thin coal-seams, and the strata rest generally directly on Old Red Sandstone; but representatives both of the Carboniferous Limestone and Millstone Grit are interposed at the eastern side of the Titterstone Hill.

I have referred to these districts more on account of their geological interest than for any economical value they may be supposed to possess.

* See horizontal section of the Geological Survey, Sheet 36.

CHAPTER VI.

COAL-FIELD OF COALBROOK DALE, SHROPSHIRE.

THIS coal-field has a triangular form, with its base in the valley of the Severn, near Coalbrook Dale, and its northern apex at Newport. Along its western side it is bounded partly by a great fault, which brings in the New Red Sandstone, and partly by the Silurian rocks of the Wrekin, which rises with its smooth and arched back to the height of 1,320 feet above the sea, and half that amount above the general level of the country around. Along its eastern side the coal-field is bounded by Permian strata, under which the Carboniferous beds appear to pass, but diminished both in thickness and in productiveness of coal.

The general dip of the strata is eastward; and in making a traverse to the foot of the Wrekin we cross in succession the base of the Coal-measures, the Millstone Grit, Carboniferous Limestone, a bed of basalt, and at length reach Silurian rocks, which form the general foun-

dation to the Carboniferous formations in this district. This succession of strata is illustrated by the section (Fig. 7, p. 144), in which, however, the denudation of the lower measures, and their overlap by the upper, is omitted; the drawing being too small for the insertion of these phenomena.

Surveys and Descriptions.—This coal-field is alluded to by the late Sir R. Murchison,* who notices some of its peculiarities; and is the subject of an elaborate memoir by Professor Prestwich, F.R.S.,† accompanied by a map and numerous sections. It was afterwards surveyed by the officers of the Geological Survey.‡ More recently additional light has been thrown on its structure by Mr. Marcus W. T. Scott,§ Mr. Randall,|| and Mr. D. Jones.¶ The researches of these gentlemen have thrown much light on the nature of the "Symon fault," and the relations of the Upper to the Lower Coal-measures, and of the Permian rocks to both.

* "Silurian System," p. 86, 1839.

† Geol. Trans., 2 ser., vol. v., 1840.

‡ Geol. Survey Maps, 61, N.E., and Horizontal Section, Sheets 54 and 58, with explanatory notices.

§ Journ. Geol. Soc. Lond., vol. xvii., 457 (1861).

|| Letters published in the *Mining Journal*, 1871.

¶ Geol. Mag., vol. viii., p. 200 (1871).

PITS IN THE COALBROOK DALE DISTRICT.

(*Those which are numbered are shown on the Map*, PLATE III. *Reduced from that of Mr. D. Jones.*)

1. Lodgewood.
2. Granville Pit. } Sections by Doody.
3. Donnington Wood.
4. New Hadly.
5. Wombridge.
6. Nelson Pit, Prior's Lee (from Stone Coal). } Geological Survey, Vertical Sections, No. 23.
7. Ketley. Prestwich, p. 445, "I am not aware of its existing farther to south than New Hadley and part of Ketley."
   Wombridge, Townson's Tracts. *Vide* Prestwich.
8. Snedshill. Prestwich, p. 478.
   Edwards Piece, Hadley. Prestwich, p. 480.
   New Hadley. Prestwich, p. 481.
   Tub Engine Pit, Donnington Wood. Prestwich, p. 483.

The following range from the Top Coal, Double and Yard Coals, downwards:—

9. Lawley and Steeraway.
   Horsehays.
   Rickyard Pit, Prior's Lee.
10. Lawn Pit, Malinslee.
11. Pudley Hill.
   Portley Pit, Dawley.
12. Deepfield Pit, Dawley.
13. Madeley Court. } Geological Survey, Vertical Section, Sheet 23.
14. Stafford Pit. Doody.
15. Kemberton Pit. W. Ward.
16. Halesfield. M. Scott.
   Lightmoor Whinney Pit. Prestwich, p. 475.
17. Little Wenlock. Prestwich, p. 477.
   New Works, New Lawley. Prestwich, p. 477.
18. Langley. (Double Coal.) Prestwich, p. 478.
19. Old Works at Dawley. Prestwich, p. 480.
   Wombridge Pit, near the engine. Prestwich, p. 480.
   Holywell Pits, Malinslee. Prestwich, p. 482.
   Dawley Pit. Prestwich, p. 483.
   Old Park Pits. Prestwich, p. 483.

The following pits range from the Lower Pennystone or Big Flint Coal:—

Hills Lane.
20. Broseley. } Vertical Section, Sheet 23.
21. Trial Pit, Castle Green. Prestwich, p. 475.

22. Lodge Pit, Madeley. Prestwich, p. 477.
Trial Pit, near Lilleshall Old Hall. Prestwich, p. 479.
Hemans Pitfield, near Broseley. Prestwich, p. 481.
Yew Tree Pit, Calcut Field, Broseley. Prestwich, p. 481.
23. Meadow Pits, Madeley. Prestwich, p. 485.
Hills Lane (with the local terms). Prestwich, p. 486.

The following range from the "Best" coal and below :—

Caughley. Vertical Section, Sheet 23.
Limestone Pits, Lincoln's Hill. Prestwich, p. 480.
24. Amies Field, near Broseley. Prestwich, 478.
25. Inett. Prestwich, p. 478.

Succession of Coal-seams, Coalbrook Dale.

			Ft.	In.	Ft.	In.
1.	Chance Pennystone coal.	(*Found only at north end of Coal-field.*)				
2.	Fungus Coal.					
3.	Gur coal.					
4.	Top coal	from	4	0 to	4	6
5.	Half Yard coal				1	6
6.	Double coal	,,	5	0 ,,	6	0
7.	Yard coal	,,	2	6 ,,	3	0
8.	Big Flint coal	,,	3	0 ,,	4	6
9.	Stinking coal	,,	3	0 ,,	4	0
10.	Clunch coal				2	0
11.	Two feet and Best (with parting)				3	4
12.	Randle and Clod coal	,,	4	0 ,,	5	0
13.	Little Flint coal	,,	1	6 ,,	2	3

The whole of the above seams of coal are contained in a series of strata about 1,000 feet in vertical thickness.

The Symon fault; denudation of the Middle and Lower Measures.—At the time when Mr. Prestwich was engaged in his investigations,

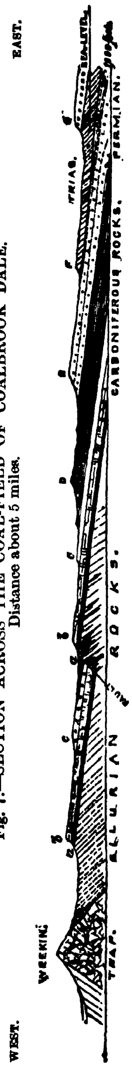


Fig. 7.—SECTION ACROSS THE COAL-FIELD OF COALBROOK DALE.
Distance about 5 miles.

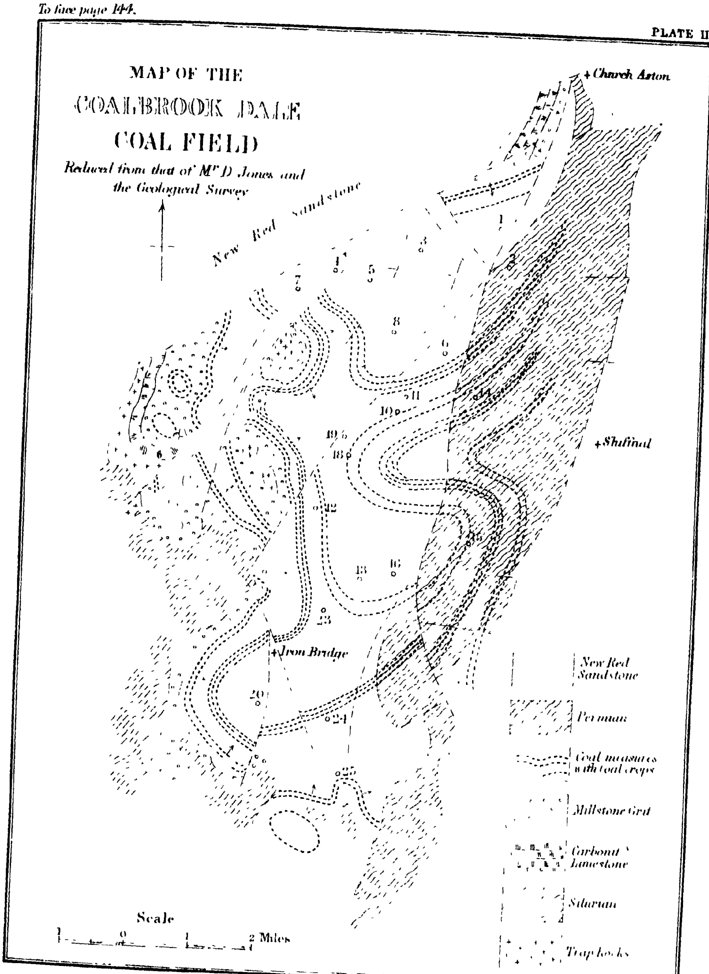
D. Coal-measures, with coal.
c. Millstone Grit.
b. Carboniferous Limestone.
a. Basalt.
E. Permian Rocks.
F. G. New Red Sandstone. { G. Conglomerate. F. Lower Mottled Sandstone.

it was known that several of the seams of coal and ironstone had a very limited range, and appeared to die out in certain directions. Thus it appears that the three uppermost seams in the above list of coals are only found in the northern part of the coal-field; that the Top Coal and Yard Coal are limited to the central portions; and finally, that the upper measures with the "Spirorbis limestone" are found at the southern end of the field, within 170 feet (vertically) of the base of the Coal-measures.

The observations of Messrs. Scott and Jones appear very satisfactorily to account for these peculiar conditions. According to their views, founded on actual knowledge of pit-sections and underground works, there has been a considerable amount of denudation of the coal-

To face page 144.

PLATE III.



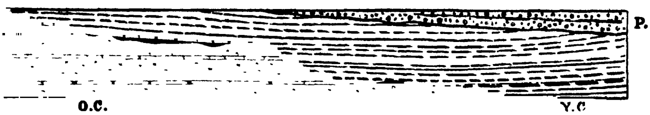
London Edward Stanford 55, Charing Cross.

series at a certain stage of the coal-period, and after all the strata up to, and including, the "Chance Pennystone" had been formed. In the hollow portions of the coal-field thus formed, the Upper Coal-measures appear to have been deposited; their junction with the older strata being a sloping bank, or cliff, and the line of separation being marked by the presence of a bed of gravel and a mottled clay locally known as "Calaminker." The relations of these different portions of the same formation will be better understood by reference to the section below (Fig. 8), taken from Mr. Jones's paper, and by the Sketch Map, Plate III.

Upper Coal-measures.—These strata are found extending from the northern portion of the coal-field along the eastern side to the banks of the Severn, and consist of mottled clays, greenish grits, and calcareous gravel or breccia, resembling volcanic ashes. In these beds the remarkably persistent band of compact limestone, with *Spirorbis Carbonarius*, first described by Sir R. Murchison, is found, and has been traced southwards along the valley of the Severn into the coal-field of the Forest of Wyre. The boundary with the Permian rocks along the east appears, in some places at least, to have the

character of an inclined bank, due to denudation.

Fig. 8.—SECTION SHOWING RELATIONS OF THE MIDDLE AND UPPER COAL-MEASURES, COALBROOK DALE.



O.C. Older Coal-measures. Y.C. Younger Coal-measures. P. Permian Beds.

The strata of this coal-field are much broken by faults. The largest of these is the western boundary fault; another, the *Lightmoor fault*, traversing the centre of the coal-field from north to south, has a "throw" of about 100 yards: west of this fault the coal-beds are almost exhausted. There are also many transverse fractures.

Organic Remains.—These are extremely varied, and have been enumerated in detail by Mr. Prestwich. They occur principally in the ironstones, of which the principal depositories are the Pennystone and Crowshaw bands. Fish: *Hybodus*, *Gyracanthus formosus*, *Cochliodus*, *Megalichthys*, *Hibberti*, *Pleuracanthus*. Crustacea: *Limulus*, a genus allied to the king-crab; *Glyphea*, *Leperditia inflata* (Bean). Mollusca: *Nautilus*, *Orthoceras*, *Bellerophon*, *Conularia*, *Spirifer bisulcatus*, *Productus scabriculus*, *Aviculo-pecten*, *Anthracosia* (Unio), *Ctenodonta* (or

Nucula), *Lingula*, *Rhynchonella*. Insects: one or more species of scorpion; two beetles of the family *Curculionidæ*, and a neuropterous insect, resembling the genus *Corydalis*, and another related to the *Phasmidæ*.*

There are several courses of ironstone measures, which in 1878 yielded 80,965 tons of pig-iron, from 11 blast furnaces; † the Coalbrook Dale and Lilleshall companies being the largest producers.

The coal under a very large portion of this field has been nearly exhausted, as will be apparent to any one who crosses it by the Wolverhampton and Shrewsbury railway, where over a large area, dismantled engine-houses, and enormous piles of refuse from abandoned coal and iron mines, meet the eye. The collieries have gradually migrated from the western outcrop towards the east. Under these circumstances, it is probably within the mark to deduct from the original mass of coal two-thirds for the quantity already worked out. Nearly twenty years back, when Mr. Prestwich was engaged in his survey, the district west of the Lightmoor fault was almost destitute of coal.

* Lyell, "Elem. Geol.," p. 388.

† "Mineral Statistics," 1878.

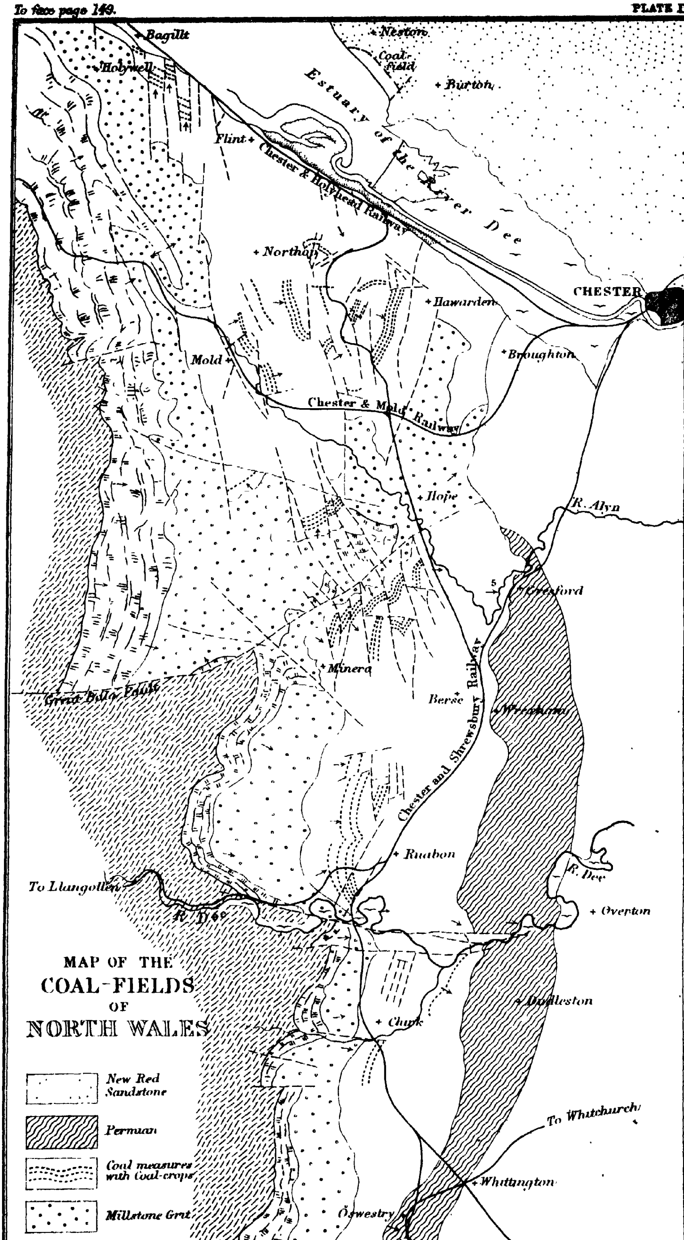
*Resources.**

1. Area of the coal-field . . .	28 square miles.
2. Greatest thickness of coal-measures	1,200 feet.
3. Number of Coal-seams of upwards of 2 feet in thickness, 6, giving a total thickness of . . .	27 feet of coal.
4. Original quantity of coal (corrected for denudation)	43 millions of tons.
5. Total quantity worked out and lost, about 31 millions, leaving for future use	12 ,, ,,

The quantity of coal raised in 1878 amounted to 830,575 tons.

This estimate only applies to the actual coal-field. As already stated, the Coal-measures pass under Permian and New Red Sandstone along the eastern margin, and already have these rocks been invaded by at least three collieries, namely, the Granville Pits, the Stafford Pits, and the Kemberton Pits.

* I have made very little alteration in my original estimate of the resources of this coal-field, now rapidly approaching exhaustion. Owing to the estimates of the quantity of coal being combined with those of Staffordshire and East Worcestershire, in Mr. Hartley's Returns, published in the Report of the Coal-Commission, I am unable to substitute them for my own. The estimates of the quantity of coal under the district lying between this coal-field and those of South Staffordshire and North Staffordshire, drawn up by Professor Ramsay, amount to 10,380,000,000 tons. This area embraces an extent of 395 square miles.—Report, p. xi.


Bagillt
Holywell
Neston
Coal-field
Burton
Estuary of the River Dee
Flint
Chester & Holyhead Railway
Northop
Hawarden
CHESTER
Broughton
Mold
Chester & Mold Railway
Hope
R. Alyn
Gresford
Minera
Great Bala Fault
Berse
Wrexham
Chester and Shrewsbury Railway
Ruabon
To Llangollen
R. Dee
R. Dee
Overton
Chirk
Bangor
To Whitchurch
Whittington
Oswestry
MAP OF THE
COAL-FIELDS
OF
NORTH WALES
New Red Sandstone
Permian
Coal measures with Coal-crops
Millstone Grit

CHAPTER VII.

THE COAL-FIELDS OF NORTH WALES.

General Structure.

An interrupted tract of Coal-measures extends from the northern slopes of the valley of the Severn, south of Oswestry, to the mouth of the estuary of the river Dee, in Flintshire, crossing the river at the entrance to the Vale of Llangollen. The Coal-measures are overlaid by Permian strata on the south, and New Red Sandstone on the north, and repose on beds of Millstone Grit, Yoredale Shale, and Carboniferous Limestone, each about 1,000 feet in thickness.* These form a range of lofty hills with terraced escarpments looking westward, and exhibit a

* The observations of Mr. Green of the Geological Survey (Geol. Mag., vol. iv., p. 11), and of Captain Aitken (*Ibid.*, vol. vii., p. 263), tend to prove that a portion, at least, of the beds intervening between the lower Coal-measures of North Wales are referable to the "Yoredale Series," as understood by the officers of the Geological Survey. Mr. D. C. Davies and Mr. W. Prosser have obtained numerous fossil shells, etc., from these beds.

very noble and striking feature when viewed from behind Llangollen, when they assume the form of a long line of ramparts, the strata being piled like lines of masonry, tier above tier. This rampart forms the physical line of demarcation between Wales and England, though the conventional boundary extends into the plain along the eastern slopes.

These calcareous hills are frequently traversed by faults, and are full of lodes rich in argentiferous galena; the most remarkable of which is the "Great Minera vein," coinciding with a line of fault traversing the Denbighshire coal-field from south-east to north-west, and which in 1869 yielded 5,447 tons of ore.

The coal-fields here described form part of the counties of Denbigh and Flint; and north of the valley of the Alyn become separated into two portions, by the upheaval along the line of a great fault of the Lower Carboniferous Rocks.* The tract south of this fault is called the "Denbighshire coal-field"; that to the north, the "Flintshire coal-field"—each of which will now be described separately.

* This is one of the largest faults in Britain, and has been traced from the sea on the coast of Merionethshire, through Bala Lake, into Cheshire. See Maps of Geological Survey, Sheet 74, N.E. and S.W.

DENBIGHSHIRE COAL-FIELD.

This coal-field commences about three miles south of Oswestry, where the New Red Sandstone begins to rest directly on the Millstone Grit, and extends northward by Oswestry, Ruabon, and Wrexham, to the north of the valley of the Alyn, which winds through a deep defile, and exposes in its banks an almost complete section of the coal-formation. The length of the coal-field is about eighteen miles; and it is about four miles in breadth at Wrexham, where crossed by the section. (Fig.9, p. 154.)

The general succession of the strata is as follows :—

		Thickness.
1. Trias, or New Red Sandstone.		1,200 ft.
2. Lower Permian rocks (thinning northwards)		1,000 to 2,000 ,,
3. Coal-measures	1. Upper series, 1,000 feet. 2. Middle (with coals), 800 feet. 3. (Lower thin coals), 1,000 feet.	2,800 ,, 3,000 ,,
4. Millstone Grit and Yoredale Beds .		800 ,, 1,000 ,,
5. Carboniferous Limestone . . .		1,000 ,, 1,500 ,,

The Lower Permian strata consist of red and purple marls and sandstones, sometimes calcareous, and may be seen along the banks

of the Dee west of Overton, and in the brook which flows eastward of Wrexham.

The Coal-measures may be classed under three divisions. The upper, consisting of red and grey sandstones and reddish clays, and containing only a few very thin and worthless coals: of these beds there are good sections along the banks of the Alyn, west of Cresford. The middle series constitutes the coal-bearing strata, and contains the following coal seams of good quality, besides several others not worth mentioning: this series corresponds, with slight variation, to that in Flintshire:—

*Succession of Coal-seams, Denbighshire Coal-field.**

	Yds.	Ft.	In.
1. *Top Sulphurous Coal* (not worked) .	0	4	0
Strata	70	0	10
2. *Bottom Sulphurous Coal* (not worked)		4	6
Strata	10	0	7
3. *Smith's Coal*		2	2
Strata	12	1	1
4. *Drowsall Coal* (good quality) . .		3	0
Strata	9	0	8
5. *Powell Coal*		3	3
Strata	9	1	3
6. *Two Yard Coal*		6	0
Strata	11	0	0

* This section was furnished to me by Mr. Napier, Manager of Westminster Colliery, 1859.

	Yds.	Ft.	In.
7. *Crank Coal*		2	8
Strata, with Brassy Ironstone .	10	2	6
8. *Brassy Coal*		5	0
Strata, with black-band ironstone, 18 inches	10	0	11
9. *Main Coal*, with a parting of clay, 15 inches . . .		7	5
Total	156	0	10

The lower measures contain several coal-seams, varying from 2 to 3 feet, which have been but little sought after in the presence of the thick seams from the middle series.

There are several valuable beds of ironstone, the principal being "the brassy" and "black-band" seams.

The remains of fish are abundant in this coal-field, and have been classed by Sir P. Egerton under the following genera: *Rhizodus*, *Cœlacanthus*, *Platysomus*, and *Palæoniscus*. The black-band ironstone is very full of fish-scales, teeth, etc., and also contains a bivalve shell of the genus *Anthracosia*. In the Lower Coal-measures the black shales contain *Goniatites* and *Aviculopecten*, as is the case in Lancashire and Yorkshire.

Though the Coal-seams are of good quality and thickness, and advantageously placed for work-

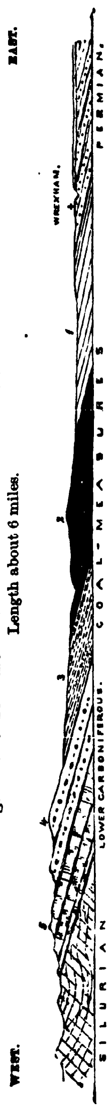


Fig. 9—SECTION ACROSS THE DENBIGHSHIRE COAL-FIELD.
Length about 6 miles.

1. Upper Coal-measures without coal. 2. Middle Coal-measures with coal. 3. Lower Coal-measures with thin coals.
4. Millstone Grit. 5. Carboniferous Limestone.

ing on a large scale, it is only within the last few years that these great resources have become recognised. In 1857 there were no very deep collieries; one of the deepest, Westminster Colliery, from which the section of the strata has been taken, being only 173 yards. Since that time several very deep shafts have been sunk, one of these at Hafod, near Ruabon, belonging to the Ruabon Coal Company, descending to a depth of over 500 yards."*

The production of this coal-field has also greatly increased within the last few years, especially since the opening of the Great Western Railway, which carries the coal direct to the London market. Probably half a million of tons are transported by this railway alone. In 1858, the quantity of coal raised in the Denbigh-

* This colliery I had an opportunity of visiting soon after the first shaft had successfully won the Main coal in 1868 or 1869.

shire coal-field amounted to only 527,000 tons; it now reaches over one and a half million, from 54 collieries.*

Resources.

1. Area of the coal-field . . .	47 square miles.
2. Greatest thickness of coal-measures	3,000 feet.
3. Number of workable coal-seams from 2 feet and upwards, 7; giving a thickness of . .	30 feet of coal.
4. Quantity of coal unwrought, and likely to be clear for working to a depth of 4,000 feet . .	1,260 millions of tons.†

* In 1869 the quantity was 1,427,701 tons. ("Mineral Statistics," 1869, p. 129.) In the returns for 1878, the output from all the North Wales collieries amounted to 2,222,257 tons.

† The estimate of Mr. Dickinson, 287 millions, from which I have deducted 12 millions for the quantity since worked out. (Rep. Coal-Commission, vol. i., 18.) My own estimate, as given in the 2nd edit. of this work, was 490 millions of tons to a depth of 2,000 feet, and half as much more to a depth of 4,000 feet.

CHAPTER VIII.

FLINTSHIRE COAL-FIELD.

THIS coal-field is disconnected from that of Denbighshire by the upthrow of Carboniferous Limestone and Millstone Grit over a small tract between Gresford and Hope. From this it extends along the western side of the estuary of the Dee to Point of Aire, a distance of 15 miles; but throughout a considerable part of its range the productive portion is very narrow, and greatly broken by faults.

The general dip of the beds is towards the north-east, and there is no doubt but that they underlie the New Red Sandstone of the Cheshire plain; for they actually reappear on the Cheshire coast at Parkgate, where they are upheaved along a line of fault.*

* Map of the Geol. Survey, 79, N.E. Also Section Sheet 43, with description. For much information regarding this coal-field I am indebted to the late Mr. Beckett, of Wolverhampton, and to Mr. P. Higson, of Manchester.

The following is the general section of this coal-field :—

		Ft.	In.
1.	*Four-foot coal* { Coal / Cannel }	4	0
	Strata.	41	0
2.	*Bind coal*	2	6
	Strata, with ironstone	62	0
3.	{ *Hollin coal* (in three beds)	6	6
	{ Cannel	1	6
	Strata, with ironstone	29	0
4.	*Brassy coal*	3	0
	Strata	32	0
5.	*Main coal*	7	0
	Strata	180 to 300	0
6.	*Lower Four-foot coal* (in some places, *cannel*)	4	0

It will be observed that the *Main* and *Brassy* coals of Flintshire and Denbighshire correspond; that the "Hollin" coal of the former is the "Two-yard" coal of the latter, while the "Powell" coal represents the "Bind" coal. The intermediate ironstone-measures also correspond with those of Denbighshire.

The lower Four-foot coal is considered to be the same as the cannel seam of Leeswood, near Mold. It is exceedingly valuable, owing to the large quantity of oil which it yields on distillation; and it is said to yield a larger quantity of gas

than the celebrated Wigan cannel.* Its position is about 100 yards underneath the Main coal, and its character as cannel (or gas coal) is considered to be limited to a comparatively small area.† The following is the section of the strata accompanying this seam:—

		Yds.	Ft.	In.
Black shale	. . .	3	2	8
Light shale	. . .	0	0	7
Black bass	. . .	0	0	7
Top cannel	. . 2 ft. to	0	2	2
Curley cannel	. 1 ft. 6 in. to	0	1	8
Bad cannel	. . .	0	1	5
Black shale	. . .	0	3	0

The following is a condensed section of the formation taken at Mold, Flintshire: ‡—

	Yds.	Ft.	In.	Yds.	Ft.	In.
Strata from surface . .	48	1	6	48	1	6
Hollin coal	2	0	2	50	1	8
Brassy coal	1	0	0	71	1	8
Rough coal	1	0	0	88	2	2
Main coal	3	2	0	103	1	2
Coal	1	0	0	107	1	2
Coal	1	1	0	113	2	2

* According to the assay of Dr. Andrew Fyfe, the proportions are as follows: Wigan cannel, 12,010 cubic feet per ton; Leeswood curley cannel, 14,280; and Leeswood smooth cannel, 9,972. Of course these proportions are liable to variation.

† In 1878, the quantity of oil-shale raised in Flintshire was 3,653 tons (Min. Stat. 1878, p. 148).

‡ For which I am indebted to Mr. H. Beckett, F.G.S.

	Yds.	Ft.	In.	Yds.	Ft.	In.
Strata, with several seams of ironstone	20	2	0	134	1	2
Coal	1	1	0	135	2	9
Coal	1	2	0	151	1	9
Shale	1	2	0	153	2	9
Coal { Coal . 2 0; Bass . 0 10; Coal . 2 6 } .	1	2	4	155	0	1
Coal	0	2	0	179	2	1
Cannel coal.	1	0	6	196	0	7
Oil shale, 15 ins.; black-band ironstone, 6 ins. . .	0	1	9	196	2	4
Wall and Bench coal { Coal 0 1 0; Shale 0 0 6; Coal 0 1 4 }	0	2	10	219	2	6

In the Lower Coal-measures, below all the strata above-named, Mr. Binney informs me that there are several thin seams with roofs of black shale, containing *Goniatites* and *Aviculopecten*, corresponding to the Gannister coals of Lancashire and Yorkshire. These coals are visible in a brook section south of Hope, which in another part displays very beautifully the unconformable superposition of the New Red Sandstone on the Lower Coal-measures.

The strata of the Flintshire coal-field rarely attain a great depth. If we cross the centre of the district from west to east, we find the beds repeatedly upheaved along dislocations ranging

north and south. The result is, that the greater portion of the coal being placed so near the surface has already been exhausted, and probably not more than one-half remains for future use. The valley of the Dee seems to offer favourable positions for deep shafts; and already the coal is being won under high-water mark on Mostyn Bank.

There can scarcely remain a reasonable doubt of the continuation of the coal-formation from Flintshire to Lancashire and Cheshire under the intervening tract of the New Red Sandstone. The Promontory of Wirral, lying between the estuaries of the Dee and the Mersey, may be regarded with little hesitation as a coal-field concealed by New Red Sandstone, in which the depth will be found to depend on the thickness of that formation, the structure of which has been worked out with much care by the Geological Surveyors.* Coal has actually been proved on the east side of the river Dee north of Chester, as well as at Neston; and the late Mr. Woodhouse successfully carried down a shaft into the coal-seams at some distance from the shore opposite Bagillt, near Flint.

* This is also the view of the Coal-Commissioners, as expressed by Professor Ramsay.—Report, vol. i., 127.

Resources.

1. Area of coal-field . . .	35 square miles.
2. Number of coal-seams at least 6, giving a thickness of . .	35 feet of coal.
3. Unwrought and available quantity of coal (including the tract along the estuary of the Dee, and the coal-field of Neston, in Cheshire)	710 millions of tons.

The quantity of coal raised in 1878 was 707,785 tons, from 51 collieries; the production is stationary or on the decline. The quantity of coal in the actual and visible coal-field can scarcely last more than half a century; but there are doubtless large supplies lying below the New Red Sandstone in the direction of the dip of the strata, and the borders of Cheshire.

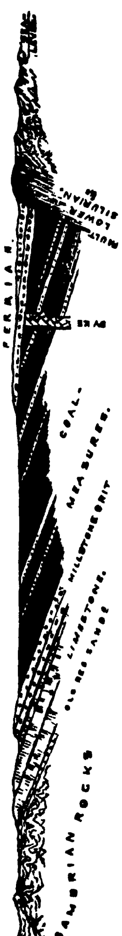


Fig. 10.—SECTION ACROSS THE ANGLESEA COAL-FIELD.
(Reduced from Section of the Geological Survey.)

CHAPTER IX.

ANGLESEA COAL-FIELD.

CROSSING a mountainous region of 45 miles in breadth from the Flintshire coal-field to the centre of Anglesea we find a series of Carboniferous strata, on the whole, similar to those just described.

The Anglesea coal-field forms a band of country stretching from Hirdre-faig to Malldraeth Bay, a distance of nine miles. Its breadth at Malldraeth Marsh is a mile and a half. The Coal-measures are overlaid unconformably by red sandstone, conglomerate, and marl, of Permian age; and from beneath the coal-strata the Millstone Grit and Carboniferous Limestone rise in succession, their base resting on highly-contorted and meta-

morphic schists of Cambrian or Lower Silurian age. The existence of this coal-tract is entirely due to an enormous fault, having at one point a down-throw on the north-west of 2,300 feet. On approaching this fault the coal-seams rise towards the south-east at a high angle; and through its agency the Carboniferous strata have been relatively lowered, and are protected on all sides by the ancient Silurian rocks. (See Section, Fig. 10, page 162.)

The following is the general succession of the strata as determined by Professor Ramsay: *—

Succession of Strata, Anglesea Coal-Field.

		Ft.	In.
Permian Rocks	Red Sandstone, marl, and conglomerate	195	0
Coal-measures—1,309 feet.	*Coal* ("Glopux") lying in lumps	9	0
	Shale	51	0
	Coal	3	0
	Shale	63	0
	Coal	4	0
	Strata	75	0
	Coal (irregular)	2	0
	Strata	43	0
	Coal	6	0
	Strata	90	0
	Coal (with cannel roof)	1	8

* Descriptive explanation of Section of the Geological Survey, Sheet 40; also Geol. Map, Sheet 78.

		Ft.	In.
	Strata (about)	300	0
	Coal (supposed Berw Uchaf coal, in three beds, with partings) .	7	6
	Strata.	650	0
Millstone Grit—	*Coal* (perhaps in Millstone Grit) .	2 to 3	0
	Yellow sandstone and conglomerate	200	0
Carboniferous Limestone.	Gray and black limestone and sandstone, with *Productus*, *Spirifer*, Corals, etc.	450	0

Some of these coal-seams crop up against the base of the Permian strata, proving the great discordance between the formations. A greenstone dyke rises in a line of fault near Berw colliery, but appears not to enter the Permian strata.

Mr. Dickinson estimates that there are 5,000,000 tons of available coal remaining in this coal-field, worked by two or three little collieries, which in 1878 produced 672 tons.*

* Hunt's "Mineral Statistics," 1878.

CHAPTER X.

SOUTH STAFFORDSHIRE COAL-FIELD.

THIS coal-field extends from the Clent Hills on the south to Brereton, near Rugeley, on the north, a distance of 21 miles, and is of an average breadth of seven miles. It appears to have been upheaved bodily along two great lines of fracture, which range in approximately parallel directions from north to south. Beyond these lines, Permian and Triassic rocks set in.*

Aspect of the Coal-field.—This district has been one of extreme productiveness in coal and iron; and its proximity to the towns of

* The earliest description of this coal-field appears to have been that of Mr. Kier, the friend of Whitehurst, who produced an able memoir on the coal, limestone, and trap-rocks of South Staffordshire, published in Shaw's History of that county, towards the end of the last century. The Dudley and Midland Geological Society is doing useful work in collecting data, and noting fresh openings in the strata, with a view to a possible new survey on the larger scale of six inches to one mile which has been carried out in the northern coal-fields.

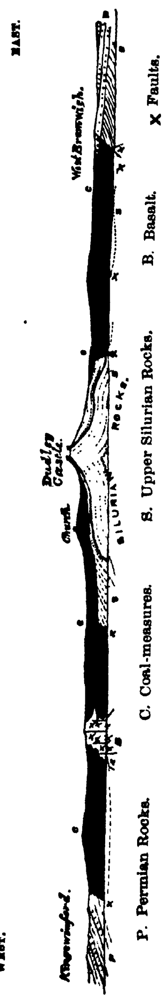


Fig 11.—SECTION ACROSS THE SOUTH STAFFORDSHIRE COAL-FIELD.
Distance about 6 miles.

Wolverhampton, Dudley, and Birmingham has imparted an extraordinary impetus to these centres of industrial pursuits. But, indeed, it may be said that the whole line of country connecting these towns, a distance of 12 miles, forms one great workshop; and on a fine night, the spectacle from the walls of Dudley Castle, which rises from the centre of the coal-field, is one which has scarcely a parallel. The whole country within a radius of five or six miles is seen to be overspread by collieries, iron-foundries, blast-furnaces, factories, and the dwellings of a dense population; and, from amidst the thick smoky atmosphere, the tongues of fire from the furnaces shoot up an intermittent light which il-

Note.—The Section at the side of this page is reduced from one by Mr. Jukes.

luminates the whole heavens. But the spectacle before our eyes does not represent the whole sum of human labour; for whilst ten thousand hands are at work above ground, one-half as many, perhaps, are beneath the surface, hewing out the coal which is to be the prime mover of the whole machinery in motion above ground.

Physical Geology.—It has been shown by the late Professor Jukes,* that while the Lower Carboniferous rocks were being deposited over other parts of England, a band of country stretching from Shropshire across South Staffordshire and Warwickshire was dry land. Consequently there is no Carboniferous Limestone or Millstone Grit; and the Coal measures repose directly on an eroded surface of Upper Silurian rocks, which, at Sedgley, Dudley, and Walsall, rise from beneath the coal-formation in a series of isolated hills. These bosses of Silurian rocks indicate the proximity of that ridge of land which formed the original limit towards the south of the coal-formation of this part of England, and which is now known to stretch

* "South Staffordshire Coal-field," Mem. Geol. Survey, 2nd Edition (Preface). See Geol. Maps, 62 S.W., 62 N.W., and corresponding Sections.

beneath the Permian formation under the Clent Hills in an east and west direction. This ridge was reached in shafts sunk, by the Messrs. Dawes at Wassel Grove and Manor Farm, in search of the thick coal; it having been assumed that the coal-beds to the north of Hales Owen would be found to extend southwards beneath the Permian Rocks. No seams, however, of any importance were found in the shafts; but at some distance down, fragments of carbonized plants mixed with sandstone, gravel, and pieces of Silurian rocks were encountered, mingled with fragments of Carboniferous plants. Below these the Upper Silurian rocks were pierced for some depth.* These phenomena, so discouraging to the enterprising proprietors, yet so full of interest to the physical geologist, are capable of explanation on the supposition that the shelving shore, or margin, of the Carboniferous area formed of Silurian rocks, was here reached. Another ridge of Silurian rocks has been found beneath the Permian strata along the eastern margin of the

* Professor Ramsay, Coal-Commission Report, vol. i., p. 120. An account of these trials was given by Mr. Henry Johnson, at a meeting of the "Mine Agents' Association," held in Dudley, in 1868. The cost of the two experiments was about £25,000.

coal-field, and was first described by Sir R. Murchison.*

But while trials for coal in a southerly direction towards the Clent Hills have been so unfruitful, others in an easterly direction have been attended with success. In the neighbourhood of Birmingham, the "thick-coal" has been reached (1876), in the shafts of the Sandwell Colliery Company, after persevering efforts, under the direction of Mr. Henry Johnson, and sometimes attended with discouraging appearances.

After passing through about 110 yards of Permian beds, the Coal-measures with plant-remains were met with, and ultimately "the thick-coal," 8 yards in thickness and of good quality, was reached at a depth of 418 yards.†

* "Silurian System." The late Mr. H. Beckett, F.G.S., informed me, however, that at their new colliery, at Hales Owen Abbey, the Messrs. Dawes have proved the "Thick coal," though not of its full thickness.

† A band of limestone, apparently the well-known and wonderfully persistent "Spirorbis limestone," was passed through in the upper part of the Coal-Measures, which caused a very natural panic amongst the projectors, under the impression that they had struck Sir R. Murchison's bank of Silurian Rocks (Proc. Dudley and Mid. Geol. Society, extracted from the *Salopian Monthly Illustrated Journal*, 12th September, 1876.)

Succession of Formations and Coal-series.

The general succession of the strata, as given by Mr. Jukes, is as follows:—

		Ft.
Trias—Bunter Sandstone, 1,200	1. Upper mottled sandstone	500
	2. Conglomerate beds .	500
	3. Lower mottled sandstone	200
		1,200
Permian [Lower Division] 1,000 to 3,000	1. Breccia of felstone, porphyry, and Silurian rocks. 2. Red marls, sandstone, and calcareous conglomerate.	1,000 to 3,000

Coal-measures—Southern District.

			Ft.
Upper Coal-measures—1,300		Red and mottled clays, red and grey sandstone and gravel beds	800
Middle Coal-measures—510 .	1.	*Brooch Coal*	4
		Strata, with ironstone . .	130
	2.	*Thick Coal* . . 24 to	30
		Strata, with "Gubbin ironstone"	20
	3.	*Heathen Coal*	4
		Strata, with ironstone . .	109
	4.	*New Mine Coal* . . .	8
		Strata, with ironstone . .	16
	5.	*Fire-Clay Coal* . . .	7
		Strata	30
	6.	*Bottom Coal*	12
		Strata, with several courses of ironstone	140

Upper Silurian Rocks	1. Ludlow rocks, with Aymestry Limestone. 2. Wenlock and Dudley Limestone and Shales. 3. Woolhope Limestone (?). 4. Llandovery Sandstone.

Coal-Seams.—From the above list it will be seen, that in the Dudley district there are six workable seams of coal, giving a total thickness of 65 feet. The most remarkable of these is the "Ten-yard," or "Thick coal," of a general thickness of 30 feet, and a source of enormous wealth to the district. It underlies a large area, at a moderate depth; and has either been worked out, drowned, or destroyed to such an extent, that probably little more than one-tenth remains to be won.* It is rather subject to "rock-faults," or "horse-backs," instances of which are given by Mr. Jukes; † one of which the author had an opportunity of examining at Baremoor colliery, where the whole mass of coal has been replaced by sandstone—the junction being formed of a series of interlacings of sandstone and coal.

* It is to be hoped that, as the value of the coal increases, the colliery proprietors may be induced to combine together to unwater the large tracts now flooded near Dudley; as it is only by such united action that this desirable end can be accomplished.

† *Supra cit.*, p. 167.

Thinning of the Strata southwards.—In the northern part of the coal-field, at Essington and Pelsall, the Thick coal of Dudley becomes split up into nine distinct seams, with a combined thickness of exactly 30 feet of coal; but separated by 420 feet of sandstones and shales, all of which are absent to the south of the "Great Bentley fault." This remarkable thinning out of the strata takes place in a distance of five miles from north to south, and is an additional instance of the higher amount of persistency in the thickness of the coal-seams than in the sedimentary strata with which they are associated.

Dip of the Beds.—North of the Great Bentley fault, the general dip is from east to west; and there is an extensive tract of about ten miles in length extending to Beaudesert, and three in breadth, over which the lower coal-seams lie nearly undisturbed, as those which are worked at Essington and Wyrley occupy a higher position. At Brereton there are several shafts sunk through conglomerate of the New Red Sandstone formation under which coal is extensively worked.

Cannock Chase.—Extensive mining operations have recently been commenced over the northern portion of Cannock Chase, which is partly formed

of New Red Conglomerate, and undoubtedly conceals an extensive coal-field. A pair of shafts have recently been sunk in the Huntington Valley to the "Deep coal," which was reached at 299 yards from the surface, all the shallower coals having been found in their usual positions.* One of the proprietors, Mr. M'Ghie, has favoured me with the following section of these pits, for insertion here :—

Name of Seam of any Thickness.			*Depth from Surface.*		
	Ft.	In.	Yds.	Ft.	In.
Coal . . .	2	4	27	1	3
Cannock Brooch Coal .	3	11	36	0	2
Five-feet Coal (8 in., parting included) .	5	11	75	1	9
Coal . . .	3	6	88	2	3
Old Park Coal . .	5	0	124	0	3
Coal . . .	4	2	178	0	5
Coal . . .	2	1	205	1	0
Coal . . .	2	3	208	1	2
Yard Coal. . .	3	2	220	2	0
Bass Coal . . .	4	2	243	0	3
Cinder Coal . .	3	10	265	1	3
Shallow Coal . .	9	3	271	1	8
Coal . . .	2	2	280	2	3
Deep Coal . .	4	4	299	1	2

Coals under 2 ft. in thickness omitted.

Another shaft has been sunk in the same

* From a communication from the late Mr. H. Beckett, dated 29th April, 1871. The new colliery belongs to the Cannock and Rugeley Colliery Company.

neighbourhood into the Coal-measures by the Huntington Colliery Company, which after passing through 354 feet of New Red Sandstone and conglomerate entered the Coal-measures and passed through several seams of coal, one of which is 5 feet in thickness. They are considered by Mr. F. W. North, who has furnished me with the particulars, as the representative of the Upper Wyrley series of coal-seams.

IGNEOUS ROCKS, CONTEMPORANEOUS AND ERUPTIVE.

Basalt.—In several localities over the southern portion of the coal-field, varieties of igneous rocks are found, frequently burrowing through and altering the Coal-measures, and sometimes resting upon them. The finest exhibition is the basaltic mass of Rowley Regis, or "Rowley rag," forming a hill about two miles in length, and 820 feet in height. This basalt assumes the columnar structure, affording examples of prisms as perfect as those from the Giant's Causeway in Ireland. Mr. Jukes considers that this rock has been poured out in the form of a lava-flow, during the coal-period; for the beds of coal dip under the basalt, and have been followed till found "blackened," or charred, and utterly worthless.*

* "South Staffordshire Coal-field," etc., p. 120.

At Pouk Hill, near Walsall, is another mass of columnar basalt, in which there are vertical, horizontal, bent, and radiating columns.*

Basalt or Melaphyre.—In the Lower Coal-measures, a sheet of melaphyre spreads almost without interruption from the base of Rowley Regis, through the centre of the district, to Wolverhampton, Bilston, and Bentley. This would appear to have been a lava-flow of earlier date than the basalt, but ejected from the same vent, which we may suppose to be situated near the centre of the hill. There are also beds of volcanic ashes and gravel associated with the Upper Coal-measures at Hales Owen, probably nearly contemporaneous in their formation with the Rowley basalt.

Ironstones.—The ironstones occur in beds, associated with shale, and are the principal

* The researches of Mr. S. Allport on the microscopic structure of the various trap rocks of South Staffordshire, Worcestershire, and Coalville in Leicestershire, which penetrate the Coal-measures, tend to show that these have nearly the same composition; viz., triclinic felspar (probably Labradorite), augite, titano-ferrite, or magnetite, and olivine, as essentials, with occasionally apatite and chlorite, calc spar and zeolites, the latter being of secondary formation; hence these rocks would fall under the name of "Melaphyres." See Mr. Allport's paper "On the Basaltic Rocks of the Midland Coal-fields," Geol. Mag., vol. vii., p. 159 (1870).

repositories of the fossils. The principal bands are—

1. The Pins and Pennyearth ironstone-measures.
2. The Grains ironstone, } below the Thick Coal.
3. The Gubbin ironstone, } below the Thick Coal.
4. The New Mine ironstone.
5. The Pennystone do., with marine fossils, *Productus*, *Aviculo-pecten*, *Lingula*, etc., a *Palechinus*, and fish-teeth and bones.
6. Poor Robin, and White ironstone—only local.
7. Gubbin and Balls ironstone.
8. Blue Flats, Silver Threads, and Diamond ironstone.

Fossils.—Fish: *Gyracanthus formosus* (ichthyodorulites), *Rhizodus*, *Pleurodus*, *Ctenoptychius*, *Megalichthys Hibberti*, *Cochliodus*, *Pœcilodus*. Molluscs: *Productus*, *Conularia*, *Lingula*, *Myalina*, *Anthracosia acuta* (in coal), *Aviculo-pecten scalaris*, in the Lower Measures; Annelides; and the usual Coal-measure plants.*

Resources.

In order to arrive at an estimate of the resources of this coal-field, it is necessary to consider the northern and southern halves separately; as the former contains about three-

* These fossils were determined by the late Mr. Salter, of the Museum of Practical Geology. They are similar to those of the "Pennystone" band of Coalbrook Dale.

fourths of the original quantity of coal, the latter only one-tenth.

1. Area of coal-field . . .	93 square miles.
2. Average thickness of workable coal above two feet . . .	50 feet
3. Total original quantity of coal (corrected for denudation) . .	3,072 millions of tons.
4. Of this, the Northern part contained	1,024 ,, ,,
Deduct 1-4th, leaving for future use	768 ,, ,,
5. The Southern part (south of the Bentley fault) contained . .	2,048 millions of tons.
Deduct 9-10ths, leaving about .	205 ,, ,,
6. Total quantity remaining (768+205) and after deducting for quantity worked out since 1870 . .	900 ,, ,,

Mr. Hartley's Estimates.

Mr. Hartley's estimates, drawn up for the Coal-Commission, give larger returns than those above; one reason being that seams of coal down to one foot in thickness are included, whereas I have excluded those of a less thickness than two feet.* Mr. Hartley's returns include in one sum the available quantity of coal from the South Staffordshire and Shropshire coal-fields, giving a total of 1,906,119,768 tons.† Deducting 20 millions as the proportion due to the Shropshire

* Another source of discrepancy in the results probably arises from Mr. Hartley having included "to a small extent" areas outside the boundaries of the exposed coal-fields.—Report, Coal-Commission, vol. i., p. 28. † *Ibid.*, p. 29.

coal-fields (Coalbrook Dale, Forest of Wyre, etc.), we have remaining (in round numbers) 1,880 millions of tons; which is nearly double the amount estimated by myself. Knowing that the southern limits of the coal-field are now definitely contracted, as proved by the sinkings at Wassel Grove and Manor Farm, I cannot think that my estimate falls much below what will be found ultimately to be the resources of the actual and visible coal-field. That there are tracts of coal beyond its margin, under the newer formations, is unquestionable, and if these be included (as in the case of Mr. Hartley's estimate) the available quantity will be proportionately increased.*

In the year 1878, there were raised in this coal-field 9,130,774 tons of coal, from 395 collieries. In the same year 392,949 tons of pig-iron were smelted in 55 furnaces.†

* Mr. W. Matthews some years ago estimated that the duration of "the thick coal" on either side of Dudley, at the present rate of consumption, would be only about 40 years.—Proc. Dudley Geol. Soc., pp. 34-37.

† "Mineral Statistics," 1878. The falling off in the iron-trade has been remarkable, and of a very serious character, for in 1870 there were smelted 588,562 tons of pig-iron in 114 furnaces. Any one surveying this once flourishing coal and iron district cannot but be struck with the signs of stagnation and decay which everywhere present themselves. This is partly due to depression in trade, but more so to the unreasonable demands of workmen regarding wages.

CHAPTER XI.

NORTH STAFFORDSHIRE COAL-FIELD.

THE North Staffordshire coal-field, though of smaller area than that of South Staffordshire, has vastly greater resources. The strata are about four times as thick, with twice the thickness of workable coal; and instead of being bounded on either side by downthrow faults which at one step place the coal at unusual depths, the Coal-measures of North Staffordshire dip under the Permian and Triassic rocks along a line of many miles at the south-western border of the coal-field, and under these formations coal may be obtained at a future day. More-

Fig. 12.—GENERAL SECTION ACROSS THE NORTH STAFFORDSHIRE COAL-FIELD. (*Southern portion*)

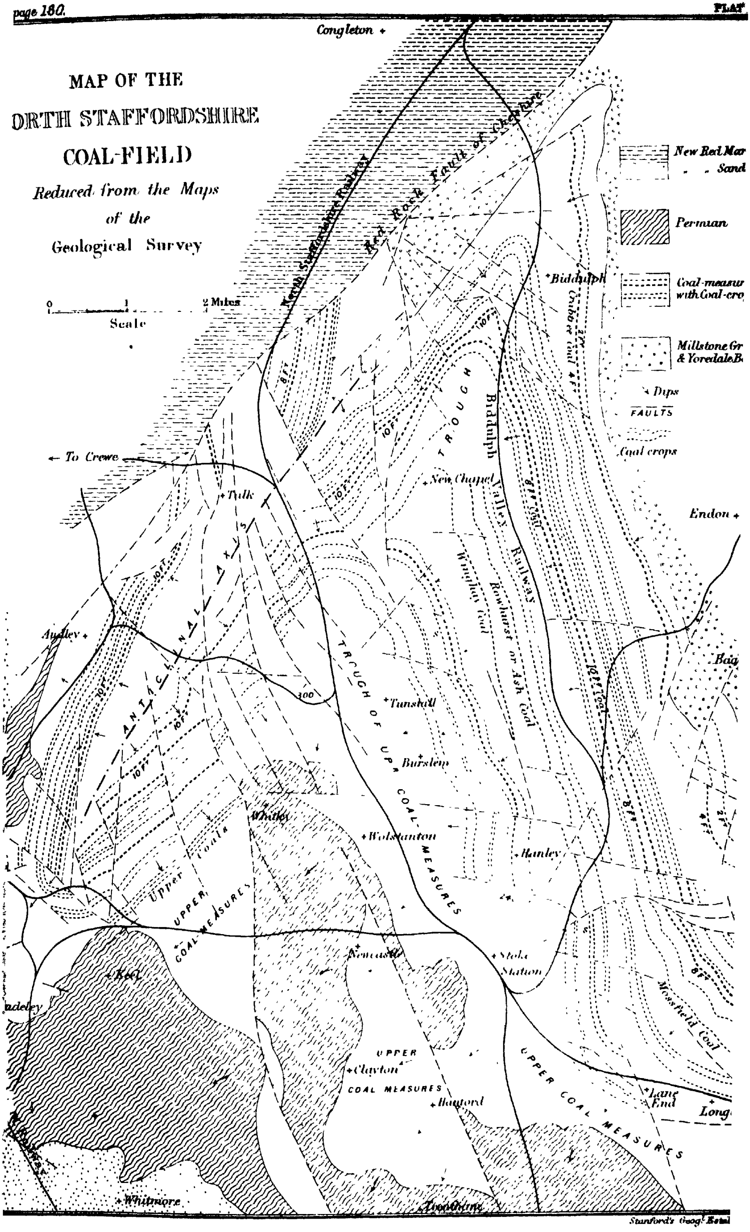
SOUTH-WEST. NORTH-EAST.

1. New Red Conglomerate. 2. Permian rocks. 3. Upper Coal-measures. 4. Middle ditto, with Coal. 5. Lower Coal-measures, with thin Coals. 6. Millstone Grit.

over, there are none of those protrusions of igneous rocks which have produced so much injury to the coal-beds near Wolverhampton, Dudley, and Hales Owen. This coal-field is in shape that of a triangle, with its apex to the north at the base of Congleton Edge; the eastern side is formed of Millstone Grit, and the western of New Red Sandstone or Permian strata. Along the south the Coal-measures are overlaid by Permian marls and sandstones, and these strata run far up into the heart of the coal-field by Newcastle, along the line of a great fault, which ranges north-north-west towards Talk-on-the-Hill.*

Structure of the Coal-field.—On referring to the map, it will be observed that along the northern and central portions the strata have been thrown into a double fold along synclinal and anticlinal axes, which appear to converge towards the apex of the coal-field at Congleton Edge; and in the opposite direction to diverge, till at the southern margin they are several miles apart. The synclinal axis is a prolongation of the Biddulph Trough, and ranges due south towards Newcastle-under-Lyne, in which direction it gradually flattens out, and further south disappears. The anticlinal (or saddle) stretches

* Map of the Geological Survey, Sheets 72, N.W. and 73, N.E.



London: Edward Stanford, 55, Charing Cross.

towards the south-south-west from Mowcop, causing a rather sharp reversal of the dip through Silverdale, and disappearing amongst the Permian and Triassic strata between Madeley and Keel. Along either side of this axis the upper coal-seams rise, and crop out, for two or three miles in nearly parallel lines; these ultimately disappear under higher strata in the valley west of Keel.

Faults.—With a few exceptional tracts, this coal-field is remarkably clear from faults; there are, however, several large lines of fracture, which have an important influence on the structure of the district. To the west of Mowcop, where the Millstone Grit emerges from beneath the Coal-measures, the coal-field is bounded by the prolongation of the "Red-rock fault" of Cheshire, which produces a down-throw to the north-west of the New Red Sandstone. This fault extends along the western base of Congleton Edge, and opposite the town of Congleton brings the Carboniferous Limestone and New Red Marl nearly into contact. Another fault of importance passes in a north-westerly direction by Newcastle and east of Hanchurch, and throws down the beds on the east to the extent of about 350 yards; a third and parallel line passing by

Hanford has a down-throw of 200 yards on the same side. East of Longton, the coal-field is bounded by a large fault, which was visible at the entrance to the railway tunnel when in course of construction; on the east side of it the New Red Sandstone is introduced.

Permian Beds.—These beds consist of purple and brownish-red sandstones, sometimes calcareous and mottled, interstratified with thick beds of red marl. They occupy a position intermediate between the Coal-measures and the New Red Sandstone, and are unconformable to both. Their unconformity to the Coal-measures is proved by the fact, that they rest indiscriminately on different portions of the formation in different localities. Thus we find them north of Madeley resting on strata of the Coal-measures about the position of the "Red Shag" ironstone; while east of Newcastle, and near Stoke-on-Trent, they rest upon beds several hundred feet above this well known band. The Permian beds attain their greatest development of 500 to 700 feet south of Newcastle-under-Lyne.

The unconformity of the New Red Sandstone to both the Permian and Carboniferous rocks is proved by even more striking cases of overlap than that above described: thus, while near

Trentham we find several hundred feet of Permian beds intervening between the New Red Conglomerate and the Coal-measures, south of Longton the former formation rests directly on the Coal-measures themselves.

*Succession of Strata, North Staffordshire Coal-field.**

			Greatest Thickness. Feet.
Permian Rocks		Red and purple sandstones, marls, and cornstones (with plants), strata slightly unconformable to the Coal-measures	600
Coal-measures—5,000 feet.	1.	*Upper*—Brown sandstones, greenish conglomerate (like the volcanic ashes of S. Staffordshire) with thick beds of red and purple mottled clays; thin coals, and a bed of *Spirorbis* limestone at Fenton†	1,000
	2.	*Middle*—Sandstones, shales, with ironstone, and about 40 coal-seams	4,000
	3.	*Lower*—Black shales and flags, with Wetley Moor thin coals, and the red ironstone of the Churnet Valley. (*Goniatites*, *Pecten.*) .	1,000

* See Horizontal Sections of the Geological Survey, Sheets 42 and 55, with Explanations. This coal-field was surveyed by Mr. W. W. Smyth, and the Author, in 1856-7. Mr. Smyth has published a full description of the coal-seams and ironstones, with their analysis, in "The Iron-ores of Great Britain," part iv. Mem. Geol. Survey.

† This remarkably persistent band was discovered by Mr. Binney, F.R.S., and Mr. J. Ward, of Longton.

	Greatest Thickness. Feet.
Millstone Grit—Coarse grits, shales, and flags . .	1,000
Yoredale Rocks—Black shales, etc., with marine fossils.	3,100
Carboniferous Limestone	4,000 to 5,000

If we compare the above section with that of South Staffordshire, we cannot but be struck by the vast accession of sedimentary materials exhibited by this coal-field as compared with the latter—an accession which, it should be observed, takes place in a northerly direction.

*Succession of Coal-seams and Ironstones.**

	Ft.	In.
Black-band ironstone (good quality) . .	1	6
Marl and bass (black shale) . . .	36	0
Red-shag ironstone (variable) . .	2 to 4	0
Coal	1	9
Marl and bass	71	6
Red Mine ironstone (good) . . .	2	3
Coal	2	0
Marl and bass	35	9
Coal	1	8
Binds, coal, and bass	62	6
Coal	1	0
Rock, binds, and bass	77	0
Coal	0	9
Marl, warrant, and rock	78	0
Bassy Mine Ironstone (good) . . .	4	0
Coal	2	0
Little Row Coal	2	2

* A valuable communication on the qualities of the coal-seams in this coal-field will be found in the Trans. Geol. Soc., Manchester, by Mr. C. Bradbury, 1861-2.

	Ft.	In.
Peacock Coal	5	8
Metal and binds (sandy shale) . . .	40	6
Spencroft Coal.	4	0
Warrant and metal (shale) . . .	53	6
Grubbin Ironstone in shale . . .	6	0
Binds	35	5
Great Row Coal	9	0
Binds, rock, and bass	78	9
Cannel Row Coal	6	6
Various strata	99	0
Wood Mine Coal	1	0
Pennystone Ironstone . .	[illegible]	0
Deep Mine ditto	0	10
Coal	3	0
Strata	69	0
Chalky Mine Ironstone	1	0
,, ,, *Coal*	1	4
Brown Mine Ironstone	0	8
Coal	1	0
Strata, with beds of ironstone . . .	59	4
Bungilow Coal	3	1
Marl, binds, and rock	108	5
Coal	1	0
Strata, with *Bay Coal*	97	3
Winghay, or *Knowles Coal* . . .	5	0
Metal and bass	35	6
Winghay Ironstone	1	5
Strata	115	8
Billy Mine Ironstone	0	6
Coal	1	6
Bind and bass	35	4
Coal	1	6
Rock, metal, and bind	34	6
Four-foot Coal	2	9
Clay, bass, and metal	50	0
Ash, or Rowhurst Coal (house coal) . .	11	6

	Ft.	In.
Marl, metal, etc.	81	3
Burnwood Ironstone	1	0
Coal	5	3
Strata	54	0
Twist Coal and Cannel	3	6
Strata	59	0
Coal	1	6
Dark metal	97	0
Strata	292	7
Birchenwood Coal (house coal)	5	3
Strata	65	6
Mossfield, or *Easling Coal*	4	0
Dark metal	34	6
Coal	2	3
Strata	61	6
Coal	2	3
Strata	129	0
Yard Coal	3	6
Binds	31	0
Ragman Coal	4	6
Strata	79	0
Banburies { *Rough 7-foot Coal*	4	3
Banburies { Strata	124	8
Banburies { *Stony 8-foot Coal*	4	0
Strata	120	0
Ten-foot Coal (strong coal)	7	0
Strata	131	0
Bowling-alley Coal	4	6
Strata	81	0
Holly Lane Coal	5	10
Strata	84	0
Sparrow Butts Coal	4	9
Strata	222	0
Flats Coal	3	0
Strata	108	0
Frog's Row Coal	4	6

	Ft.	In.
Strata	80	0
Cockhead Coal.	4	6
Strata	420	0
Bullhurst Coal	4	0
Strata	60	0
Winpenny Coal	3	0

Lower Coal-measures.—These beds, occupying a band of country on the dip of the Millstone Grit, contain two seams worked at Wetley Moor, of a thickness of 4 feet and 3 feet respectively. Amongst these strata, which are often deeply stained with red iron-oxide, is the valuable band of iron-ore, worked in the Churnet Valley; the fossils are of marine genera.

Ironstones.—Several of the coal-seams are roofed by beds of valuable ironstone, so that both can be worked together; of these the "red shag," the "red mine," the "bassy mine," and the "deep mine," and "chalky mine" ironstones are amongst the most worthy of note. The occurrence of thick beds of excellent ironstone, forming the roof of the coal-seams, is one of the special features of this coal-field which greatly enhances its economic importance.

Fossil Remains.—Some of the beds in this coal-field are very rich in remains of fish which have been collected with much perseverance by

Messrs. Garner and Molyneux, and more recently by Mr. J. Ward of Longton. Of these, a fine series was exhibited at the Meeting of the British Association at Manchester.* The following list, from the collection of Mr. Ward, has been kindly furnished by him, having had the benefit of revision by Sir P. Egerton, one of our highest authorities in ichthyology :—

FISH.—*Megalichthys Hibberti*, *Rhizodus* (three or four species), *Holoptychius*, *Rhizodus incurvus*, *Gyrolepis* (five or six species), *Palæoniscus*, *Cælacanthus* (two species), *Platysomus parvulus*, *Pl.* (new species), *Acanthodus* (new species).

FISH-TEETH.—*Diplodus gibbosus*, *D.* (*Pleuracanthus*) *minutus*, *Horpacodus* (*Ctenoptychius*) *apicalis*, *H. pectani*, *H. denticulatus*, *Helodus simplex*, *Acrodus*, *Diplopterus affinis*, *Cladodus*, *Petalodus ;* also seven or eight of new, or indeterminate, species.

ICHTHYODORULITES.—Species of *Rhizodus Hibberti*, *Orthacanthus cylindricus* (18 inches long), *Gyracanthus formosus*, *G. tuberculatus*, *Pleuracanthus lævissimus*, *Ctenacanthus Hybodoides* (Egerton), *Leptacanthus*, *Ctenodus* (palate).

MOLLUSCS.—From a bed called the "Bay-coal bass," lying rather high up amongst the Coal-series, the following have been obtained by Mr. Ward : *Nautilus*, *Goniatites*, *Aviculo-pecten*, *Melania*, *Productus*, *Lingula*, *Discina*, and a few other forms. These are all marine genera, and indicate a temporary inroad of the sea-waters over this area. In the "Ten-foot" seam of Lord Granville's colliery at Hanley, there is a band of shale filled with the genera *Anthracoptera*, *Anthracomya*, and *Anthra-*

* Trans. Brit. Assoc., p. 103 (1859). Mr. Ward has since drawn up an account of the remarkable fossil fauna of this coal-field in a collected form from papers in the proceedings of the North Staffordshire Naturalist's Field Club (1877).

cosia, together with *Goniatites Listeri*, *Aviculo-pecten papyraceus*, *Posidonia Gibsoni*, and *Spirorbis*. The association of the former-named genera with others of known marine habits has also been observed in Lancashire, and seems to show that all are alike marine, or at least estuarine. *Aviculo-pecten* and *Goniatites* have also been observed, by Mr. Binney, in the Lower Coal-measures of the Churnet Valley.

Resources.

There are few coal-fields in the United Kingdom which, in proportion to their extent, are so richly stored with minerals, and which, owing to the arrangement of the strata towards the south and west, give promise of such high productiveness in the future. That the resources of this district—till within the last twenty years not properly recognised,—are now coming into full play, is evinced by the rapid increase in the production of coal as well as of iron. In the two years extending through 1857-59 the production nearly doubled itself; and since that time it has increased by about three-fourths, while the number of collieries has not proportionably increased; showing the larger scale upon which the mines are now being worked. I give the estimate of the actual resources, as determined, with the assistance of Mr. W. T. Craig and the late Mr. W. Cope, by Mr. Elliot, the member of the

Royal Coal-Commission appointed to report upon this district.

1. Area of coal-field (exclusive of the Cheadle and Goldsitch basins) .	75 square miles.
2. Total thickness of measures with coal	5,000 feet.
3. Number of workable coal-seams about thirty, with a thickness of available coal amounting to .	150 ,,
4. Available quantity of coal, to a depth of 4,000 feet * (in round numbers)	3,680 millions of tons.

In 1878 this coal-field yielded 4,072,416 tons of coal, raised by 145 collieries. In the same year, 25,922 tons of iron-ore were raised; from which 231,534 tons of pig-iron were smelted in 24 blast furnaces.†

* Obtained after deducting the portion due to Cheadle and Goldsitch basins from the total amount down to 4,000 feet of depth. Like all the estimates of the Commissioners, it is considerably in excess of my own, owing to thin seams being included.

† "Mineral Statistics," 1878.

CHAPTER XII.

CHEADLE COAL-FIELD, STAFFORDSHIRE.

THIS small, and slightly productive, coal-field stretches from the valley of the Churnet, on the north-east, to the hills of New Red Sandstone, which stretch in a picturesque semicircle along its southern borders. Towards this range the strata dip (S.S.W.), and on the north side of the Churnet the high moorlands of the Millstone Grit rise from beneath the Coal-formation. In the centre of the coal-field, an outlier of New Red Conglomerate reposes unconformably on the Coal-measures, and forms the site of the pretty town of Cheadle.

The following is the succession of the coal-seams :—

1. Two-yard coal.
2. Half-yard coal.
3. Yard coal.
4. Littley coal.

5. Four-foot coal.
6. Woodhead 3-feet coal.

According to Mr. Elliot, this little coal-field contained in 1870 about 104,524,000 tons of coal available for future use.*

Goldsitch Trough.—This is a narrow valley lying to the east of Wetley Rocks, composed of the red strata of the Lower Coal-measures, disposed in the form of a trough, with a north and south axis. It has a surface of area of 90 acres, and contains about 110,000 tons of coal.

Hæmatite Bed of Churnet Valley.

The Lower Coal-measures of the Churnet Valley contain two thin coals, one of which has a roof of black shale with *Goniatites* and *Aviculo-pecten.*† Below these there occurs a valuable bed of iron ore, which has been extensively worked along the valley from the outcrop, and at Froghall. In thickness it varies from 6 to 20 inches, is of a deep red colour, and contains about 35 to 40 per cent. of iron. It is imbedded in shale highly impregnated with hydrated peroxide of iron. The analysis of

* Report, Coal-Commission, vol. i., p. 27.
† Mr. Binney, Trans. Geol. Soc. Manchester, vol. ii., p. 81.

this ore by Dr. Angus Smith, from a good sample obtained by Mr. Binney, is as follows :—

Peroxide of Iron	68·610
Silica	5·490
Carbonate of Lime	18·170
Carbonate of Magnesia . .	3·723
Manganese, Alumina, and moisture	4·007
	100·000

"*The Potteries.*"—Over that portion of the coal-field extending eastward of the Permian rocks of Newcastle are situated "The Potteries," a group of populous towns, the seat of that branch of industry originated by Wedgewood. From this all parts of the world are supplied with china-ware rivalling that of Dresden; with vases and various kinds of vessels modelled after Etruscan patterns, but adorned with paintings from natural models, executed with a perfection of colouring and outline to which the Etruscans never attained; here also are produced those tesselated pavements which adorn so many of our churches and public buildings. For the production of these works of art chalk-flints are brought from the south of England, decomposing granite from Cornwall, gypsum from

Chellaston, siliceous chert from Derbyshire. The coarser kinds of earthenware, as also tiles, bricks, and pipes, are made in large quantities from the clays of the Upper Coal-measures, while the coal is at hand for heating the baking ovens, and calcining the wares. The appliances and materials necessary for the prosecution of fictile manufactures are here accessible or easily available, and have contributed to render this the metropolis of British ceramic art.

CHESHIRE COAL-FIELD.

This is a small tract of Middle and Lower Coal-measures, lying to the south of the Mersey, above Stockport. It is bounded along the west by Triassic and Permian rocks, which are brought in along the line of the "Red-rock fault of Cheshire." Including the tract formed of Lower Coal-measures, the southern termination of the coal-field is opposite Macclesfield; while the central portion lies east of Poynton, where there are extensive collieries. There are several valuable seams of coal, including the "Mill mine," 4½ feet thick; the "Sheepwash mine," the "Great mine," the "Four-feet mine," the "Silver mine," the "New mine," and the "Redacre mine," which

represents the Arley or Royley mine.* Mr. Dickinson estimated (1866) the available quantity of coal at 200 millions of tons.†

* Geology of Stockport, etc. Mem. Geol. Survey, p. 29.

† Report, Coal-Commission, vol. i.

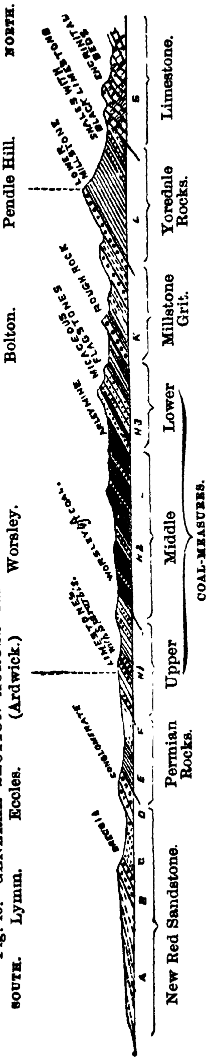


Fig. 13.—GENERAL SECTION ACROSS THE CARBONIFEROUS ROCKS OF SOUTH LANCASHIRE.

CHAPTER XIII.

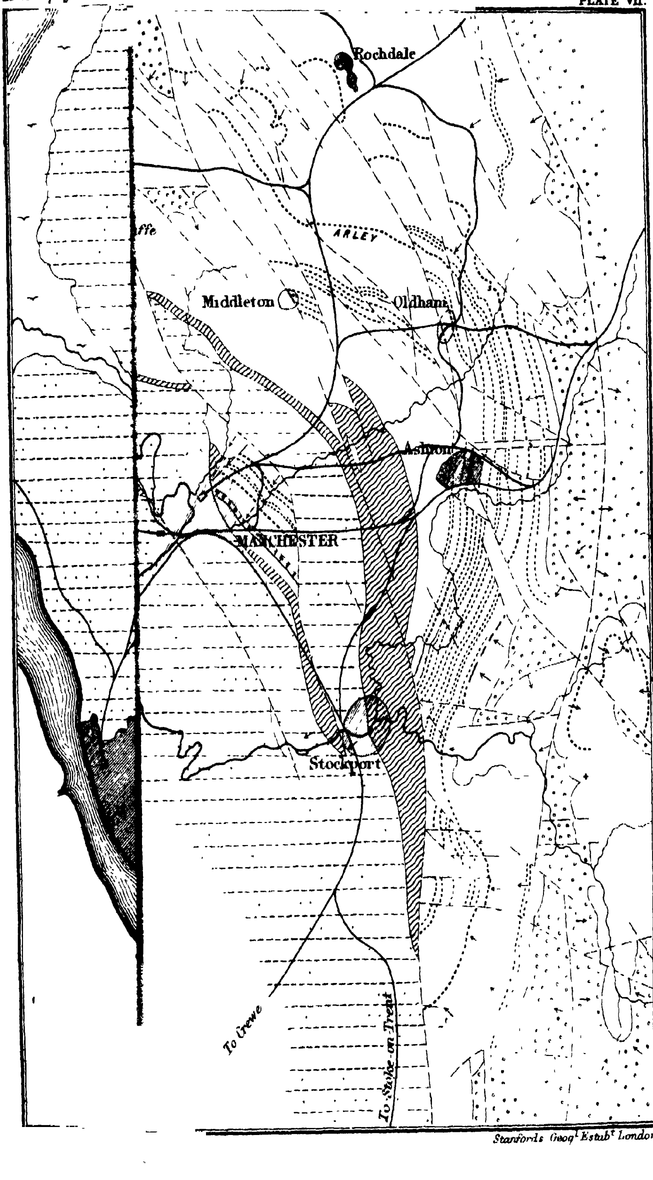
SOUTH LANCASHIRE COAL-FIELD.

(*Including East-Cheshire.*)

THIS great coal-bearing tract is very irregular in outline, and consequently difficult to describe. It may, however, be said to occupy a band of country lying east and west, sending offshoots at intervals into the Trias and Permian formations on the south, and into Lower Carboniferous strata which form its mountainous limits on the north. These offshoots are occasioned generally by enormous faults.

The extreme western boundary is a great fault, which, throwing down the New Red

PLATE VII.



Stanfords Geogl. Estabt. London.

Sandstone on the west side, ranges through Eccleston, Lathom Park, Bickerstaffe, Knowsley Park, and Huyton. To the northward the high moorlands, formed of Millstone Grit and Lower Coal-measures, traversed by deep valleys with scarped flanks, reach elevations of 2,000 feet, and stretch with a semicircular outline from Chorley to Staleybridge, by Bolton, Bury, Rochdale, and Oldham. From this elevated tract the country gradually descends towards the Valley of the Mersey, and the Coal-measures dip under the Triassic and Permian strata, which form the low-lying districts, by Rainford, Newton, Ashton-in-Makerfield, Leigh, Astley, Eccles, Manchester, and Stockport, near which point the coal-field crosses the Mersey and enters Cheshire. The extreme length from Bickerstaffe to Staleybridge is 32 miles, and the average breadth 6 miles. Smaller isolated coal-fields occur at Croxteth Park, Bradford near Manchester, and Burnley.

To what distance the southerly dip of the Coal-measures continues beyond the valley of the Mersey is unknown; but from a consideration of the relations of the Carboniferous, to the newer, formations, I regard it as probable that the beds begin to rise towards the south, and

possibly terminate along a concealed axis ranging from Chester towards Congleton, in a direction from west to east. This axis would divide the Coal-measures into two distinct basins.

General Succession of Formations.

			Maximum Thickness. Feet.
Trias, 4,750 ft.	Keuper (A, B, of fig. 13).	1. Red Marls, Cheshire .	3,000
		2. Lower Keuper Sandstone (Waterstones).	500
	Bunter (C.D.)	1. Upper Mottled Sandstone . . .	500
		2. Conglomerate beds .	650
		3. Lower Mottled Sandstone (often absent).	100
Permian Series, 355-650 feet.	1. Upper (E.)	Red marls and limestones of Leigh, Patricroft, Manchester, with *Schizodus*, *Bakevellia*, *Turbo*, *Rissoa*, *Natica minima*, *Tragos*	250
	2. Lower (F.)	Sandstone of Collyhurst, etc.	100 to 400 or more.

Note.—Several valuable memoirs on this coal-field have appeared by Mr. Binney, Trans. Geol. Soc., Manchester, vols. i. and ii., part 7; also by Mr. Bowman (*Ibid*). See also Mr. Dickinson's Vertical Section, in Report of the Inspectors of Mines for 1858. The Geological Survey of Lancashire, on a scale of six inches, and one inch to a mile, is now completed, and illustrated by explanatory memoirs and sheets of sections.

			Maximum Thickness. Feet.
Coal-measures, 6,080 ft. to 8,000.	1. Upper—(H 1.)	Shales, sandstones, and limestones of Ardwick, with *Spirorbis*, *Leperditia*, and fish of the genera *Ctenoptychius*, *Megalichthys*, *Palæoniscus*, etc.; and a bed of black-band ironstone, with *Anthracosia Phillipsii*. Below these beds are sandstones, shales, and thin coal-seams.	1,680 to 2,000
	2. Middle—(H 2.)	From the Worsley Four-feet Coal to the "Arley Mine," with *Anthracosia*, *Modiola*, fish, etc.	3,000 to 4,000
	3. Lower, or Gannister Beds. (H 3.)	Flags, shales, and thin coals, with Gannister floors and roofs of shale, with *Spirorbis*, *Goniatites*, *Nautilus*, *Aviculo-pecten*, *Lingula*, *Anthracosia*, fish, and Crustaceans (*Leperditia*).	1,400 to 2,000
Millstone Grit		From the "Rough Rock" to the lowest Millstone Grit (with thin coals) . .	3,500 to 5,000
Limestone		Shale or Yoredale Rocks, with molluscs	2,000 to 4,000

The coal-series varies considerably in different parts of the district, and there is a general thickening of the sedimentary materials, as sandstones and shales, towards the N.N.W. Thus

the *same* coal-seams are farther apart at St. Helens than at Prescot; and at Wigan than at St. Helens.

Several coals can be traced over the entire district under different names. The "Little Delf" of St. Helens is the "Arley Mine" at Wigan, the "Riley Mine" of Bolton, and the "Dogshaw Mine" of Bury. It is the lowest coal-bed of the middle coal-series, and one of great economic value. Its roof frequently contains fish remains, and some yards above it there occurs a very constant bed of ironstone filled with *Anthracosia* (*Unio*) *robusta*. Above this is the "Rushy Park" coal, which is very constant; but unfortunately the most valuable of all the coal-seams, the *Cannel Mine* of Wigan, thins away in every direction from Wigan as a centre. The Trencher Bone of Bolton is the Wigan 9-feet, and the Roger 9-feet of St. Helens.

General Section of the Coal-series at St. Helens.

(The numbers show the Coals which correspond to each other.)

	Yds.	Ft.	In.
Strata of upper Coal-measures without coal	650	0	0
Lyons Delf Coal (inferior quality) . .	0	2	8
Strata	16	2	0
London Delf Coal (inferior quality) . .	0	2	6
Strata	28	2	2
Potato Delf (inferior quality) . . .	0	5	0

		Yds.	Ft.	In.
	Strata	14	0	0
	Earthy Delf (unworkable, full of partings)	0	4	8
	Strata	94	1	0
	St. Helen's Main Coal	0	9	0
	Strata	10	2	0
	Four-feet Coal	0	3	6
	Strata	18	2	0
	Cannel	0	1	6
	Strata	92	2	0
	Coal	0	3	10
	Clay	1	1	2
	Ravenhead Main Coal	0	7	0
	Strata	33	0	0
	Bastions Mine	0	4	3
	Strata	4	1	0
	Higher Roger Coal (inferior, with partings)	0	4	0
	Strata	61	2	0
	Flaggy Delf	0	4	0
	Strata, with Lower Roger Coal	152	2	0
2.	*Rushy Park Coal*	0	4	6
	Strata	54	0	0
1.	*Arley Main* or *Little Delf*	0	3	0

General Section of the Coal-series at Wigan.

		Yds.	Ft.	In.
16.	*Four-foot Coal of Red Rock Bridge*	0	4	0
	Strata . . . . . . about	200	0	0
15.	*Ince Yard Coal*	0	3	0
	Strata, with ironstone	51	0	0
14.	*Ince* Four-feet *Coal*	0	3	7
	Strata	27	0	0
13.	*Ince* Seven-feet (with parting)	0	7	0
	Strata	23	1	0
12.	*Furnace Mine* (with parting)	0	4	7
	Strata	84	0	10

	Yds.	Ft.	In.
11. *Pemberton* Five-feet Mine	0	5	2
Strata (with a coal-seam 2 feet thick) .	25	1	0
10. *Pemberton* Four-feet Mine	0	4	6
Strata	149	0	0
9. *Wigan* Five-feet (inferior) . . .	0	4	6
Strata	21	0	0
8. *Wigan* Four-feet (with cannel) . . .	0	4	0
7. Strata, with a worthless coal called "Nine-feet Mine"	125	0	0
6. *Cannel* (best gas coal) . . from 1 to	0	3	0
Strata (variable)	1	1	0
5. *King Coal*	0	3	10
Strata	79	0	0
4. *Yard Coal*	0	3	0
Strata	50	0	0
3. *Bone Coal*	0	2	3
Strata	3	0	0
2. *Smith Coal* (Rushy Park)	0	3	6
Strata	60	0	0
1. *Arley Mine* (the most valuable next to the *Cannel*)	0	4	0

General Section between Manchester and Bolton.

(Curtailed from that of Mr. Dickinson.)

Upper Coal-measures, with seventeen beds of Coal, too thin for working . .	420	0	0
16. *Worsley Four-feet Coal* (good) . . .	0	4	3
Strata, with twenty-five seams of coal under two feet	294	0	0
15. *Bin Coal* (inferior)	0	3	6
Strata	26	0	0
Albert Mine	0	3	3
Strata	14	0	0
14. *Crumbourke Coal*	0	4	0
Strata	48	0	5

		Yds.	Ft.	In.
13.	*Rams Mine* (good)	0	5	6
	Strata, with two coal-seams under 2 feet .	84	2	7
	White Coal (good)	0	3	0
10	Strata (of variable thickness) . . .	7	0	0
	Black Coal	0	3	0
	Strata . . . . . . about	15	0	0
9.	*Old Doe Coal* (three beds, with two partings)	0	8	0
	Strata	10	1	0
8.	*Five quarters Coal*	0	3	6
	Strata (with three coals under 2 feet) .	68	2	0
7.	*Trencher Bone Coal* (3-6 to 6 feet) . .	0	5	0
	Strata	34	0	0
6.	*Cannel Mine* (cannel only 6 inches) . .	0	4	6
	Strata	19	1	0
5.	*Saplin Coal* (with parting) . . .	0	4	0
	Strata	35	6	0
	Plodder Coal (coal and shale, variable) .	0	3	0
	Strata	38	0	0
4.	*Yard Mine*	0	3	0
	Strata (with four thin coals) . . .	56	0	0
2.	*Three quarters Mine*	0	2	0
	Strata	68	2	0
1.	*Arley Mine* (with parting) . . .	3	6 to 4	6

The strata here enumerated are characterised by several bands with *Anthracosia*. From the *Cannel*, the late Mr. Peace collected splendid specimens of fish-remains, belonging to the genera *Megalichthys*, *Holoptychius* and *Ctenoptychius*.

The Lower Coal-measures.—These commence with the flagstones of Up-Holland, which lie a short distance below the Arley Mine, and extend downwards to the Millstone Grit through a series

of beds of shale, flagstone, and coal, about 1,800 feet in thickness. They are well laid open in the sections of the Wigan and Liverpool Railway. The coal-seams, three or four in number, are thin; and amongst the strata overlying the "Upper-foot," or "Bullion-coal," marine fossils of the genera *Goniatites*, *Nautilus*, *Aviculopecten*, etc., occur, as originally described by Mr. Binney.

*General Section near Oldham and Middleton. Bardsley Colliery.**

	Ft.	In.
"Bardsley Rock" (sandstone)	45	6
Shale	31	7
Stubb's Mine (coal)	1	5
Metal (shale)	25	6
Fairbottom Mine	2	0
Shale (with three seams of coal)	76	6
Park Mine (with parting of clay)	3	6
Shale	29	0
Foxhole Rock	79	8
Foxhole Mine	2	4
Soft shale	32	6
Cannel	1	6
Strata, principally shale, with a thin coal-seam	187	8
Hathershaw Mine	2	2
Shale, with two thin coal-seams	51	0
Sandstone, with water, called "Chamber rock"	88	6
Shale and sandstone	38	3

* "Geology of Oldham and Manchester," Mem. Geol. Survey, p. 24.

	Ft.	In.
Nield, or *Upper Chamber Mine*	2	0
Shale and sandstone	54	6
Lower Chamber Mine (with two shale-partings) .	4	8

The most valuable seam in the district of Oldham, Middleton, and Ashton-under-Lyne, is the "Black-mine," which is generally upwards of four feet of solid coal of good quality; and in the Astley colliery at Dukinfield* lies at a depth of 687 yards from the surface. In the direction of the Mersey, where the coal-field passes into Cheshire, the seams are generally thin, or split up by partings of shale, which render them less profitable to work at great depths. From the neighbourhood of Oldham, where the measures begin to bend round towards the south, the dip is very persistent, and at a high angle in a westerly direction; the beds here coming under the influence of the Great Pennine axis of upheaval which ranges in a north and south direction along Saddleworth Valley.

The Mountain Mines.—The coal-seams known by this name in the northern and eastern portions of the district lie in the Lower Coal-Measures. Two of them are extensively mined,

* "Geology of Oldham and Manchester," Mem. Geol. Survey, p. 27.

the "upper mountain mine, from 14 to 16 inches in thickness; and the "Gannister coal, or lower mountain mine," lying from 60 to 75 yards underneath, varying in thickness from 18 to 30 inches, and in the direction of Burnley to even more than this. Its quality is good, and it is useful for coking: it has been worked at Heywood, Rochdale, the Lancashire moors west of Todmorden, and Portsmouth, Tunshill, Crompton, Broad Car, Staleybridge, and Newton; and at New Mills and Whaley in Cheshire.

The Cheshire Coal-field.—This small coal-tract has already been referred to. It is formed of the middle and lower Coal-measures of Lancashire in their southern extension beyond the Mersey east of Stockport. It is bounded on the west by a large fault, the "red rock fault," along which the Permian and Triassic sandstones are introduced on the west. The coals are mined at Denton, Haughton, Hyde, Norbury, and Poynton, and there are several seams of good quality and thickness.*

Marine Fossils in the Middle Coal-measures.—In some large concretions shown in the banks

* "Geology of Stockport, Macclesfield, etc.," Mem. Geol. Survey, by Messrs. E. Hull and A. H. Green, to which the reader is referred for full details. See *ante*, p. 195.

of the River Tame, west of Dunkirk colliery, Ashton-under-Lyne, Professor A. H. Green, formerly of the Geological Survey, discovered a remarkable series of marine fossils, figured and described by the late Mr. Salter, in the "Geology of Oldham."* The position of this stratum appears to be above all the workable coals of Dukinfield. The following are the names of the species from this remarkable band: *Serpulites*, *Aviculo-pecten fibrilosus* (Salter), *A. papyraceus*, Sow. *Ctenodonta* (allied to *C. tumida*, *Nautilus præcox* (Salter), *Discites rotifer* (Salter), *Discites* (2 other species), *Goniatites*, *Orthoceras*, *Megalichthys Hibberti*. This is altogether a unique series from this division of the Lancashire Coal-formation in which only fossil molluscs of genera allied to *Anthracosia* are usually found.

Faults of the Lancashire Coal-field.

The Lancashire coal-field is traversed by dislocations which, although of great magnitude, produce scarcely any perceptible features at the surface—so complete have been the effects of denudation in levelling down inequalities arising from the displacement of the rocks. Over the

* Mem. Geol. Survey, pp. 32 and 64 (with plate of fossils, etc.)

southern portion of the district many of the faults slope or *hade* considerably; the general inclination being 25° from the vertical, but often more.*

The western boundary of the coal-field is a very large downthrow ranging by Ormskirk, where the Lower Keuper Sandstone and Lower Coal-measures are brought into contact.

The Great Up-Holland fault, which brings up the Lower Coal-measures so as to form an elevated band of country between the coal-fields of Rainford and Wigan, has a throw of 650 yards east of Lord Crawford's collieries.

The Coal-measures at Wigan are divided into belts, bounded by parallel faults which range N.N.W., having vertical displacements varying from 150 to 600 yards; of these the principal are the "Shevington fault," the "Cannel fault of Ince," and the "Great Haigh fault." Towards Manchester there is the "Great Pendleton or Irwell Valley fault," ranging along the valley of the Irwell (N.N.W.), bringing in the New Red Sandstone, with a downthrow on the N.N.E. of

* The fault at Red Rock Bridge, N. of Wigan, and that which bounds the little coal-field near Rainhill, are remarkable instances of very flat slopes; the angle being about 25° from the horizontal in each case.

upwards of 1,000 yards. Lastly, the great fault along which the Manchester coal-field has been upheaved on the west against the New Red Sandstone has a throw of (at least) 400 yards. All these dislocations appear to have been produced after the period of the Trias or New Red Sandstone, and the resulting inequalities of the surface have since been planed away by agents of denudation.

Fossils.

Those who are interested in the palæontology of the Coal-formation would do well to consult the carefully-prepared lists of fossils, both of vegetable and animal origin, drawn up by the late Mr. Salter, and published in the "Geology of Bolton-le-Moors," * and in the "Geology of Oldham." † Having referred to these valuable details, I shall content myself with enumerating a few species of general occurrence, most of which were first identified by Mr. Binney,‡ to whose indefatigable exertions as a collector geologists of the North of England are so much indebted.

* Mem. Geol. Survey (1862).

† *Ibid* (1864).

‡ Trans. Geol. Soc., Manchester, vol. i.

Upper Coal-measures.—Fish of the genera, *Ctenoptychius*, *Megalichthys*, *Diplopteris*, *Palæoniscus*, *Platysomus*, *Rhizodus*, *Diplodus*, and large bony rays resembling those from the limestone of Burdie House in Scotland. Crustacea: *Cythere* (Cypris) *inflata*. Annelids: *Spirorbis carbonarius*. Plants of the usual Coal-measure species.

Middle Coal-measures.—Fish: *Palæoniscus Egertoni*, *Megalichthys Hibberti*, *Rhizodus granulatus*, *Holoptychius*, *Diplopterus*, *Pleuracanthus gibbosus*, *Cœlacanthus lepturus*. Molluscs: *Anthracomya modiolaris*, *A. dolabrata*, *Anthracosia ovalis*, *A. acuta*, *A. robusta*, *A. aquilina*, *Anthracoptera Browniana*. Crustacea: *Beyrichia Binneyana*, *B. arcuata*, *Estheria striata*. Annelids: *Serpula* (?), *Spirorbis carbonarius*. Plants: *Asterophyllites*, *Calamites*, *Flabellaria*, *Halonia*, *Knorria*, *Lepidodendron*, *Lepidophyllum*, *Megaphyton*, *Nœggerathia*, *Poacites*, *Primularia*, *Sigillaria*, and *Ulodendron*. *Alethopteris*, *Cyclopteris*, *Neuropteris*, *Pecopteris*, *Sphenopteris*; and Fruits—*Lepidostrobus* and *Trigonocarpum*.

Lower Coal-measures.—Fish: *Megalichthys Hibberti*, *Cœlacanthus*, *Palæoniscus Monensis*, *P. Egertoni*, *Rhizodus granulatus*, *Pleuracanthus*. Molluscs: *Goniatites Listeri*, *G. reticulatus*, *G. Gibsoni* (Phill.), *G. paucilobus*, *Discites* (sp. inc.),

Orthoceras (sp. inc.), *Posidonia Gibsoni*, *P. lævigata*, *Monotis lævis*, *Aviculo-pecten papyraceus*, *Anthracosia ovalis*, *A. acuta*, *A. aquilina*, *Anthracoptera*, *Anthracomya*, *Lingula mytiloides*. Crustacea: *Estheria striata*, *Beyrichia arcuata*. Plants: *Alethopteris lonchiticus*, *Calamites Suckowii*, *C. undulatus*; *Daxodylon*, *Lepidodendron Sternbergii*, *L. obovatum*, *L. dilatatum*, *Sigillaria hexagona*, *S. mammilata*, *S. reniformis*, *Ulodendron majus*, *Pecopteris arborescens*, *Alethopteris lonchiticus*, *Neuropteris flexuosa*, *Nœgerathia*.

Resources of the Lancashire Coal-field.

In my original estimate of the resources of this coal-field, I thought it proper to discard from consideration the thin seams of coal belonging to the Lower Coal-measures, and known as "mountain mines." I was not then fully aware of the importance of these coals in the direction of Burnley and Todmorden, where one or two of them are of sufficient thickness to be worked at great depths, and on this ground my estimate may have been too low. I also omitted all seams under two feet in thickness, which I hold to be a proper limit for depths over 500 or 600 yards; and the result arrived at for the whole district,

including the Manchester and Burnley coal-fields, was, that there remained an available supply of 3,990 millions of tons.* Mr. Dickinson, the Commissioner who has reported on the resources of this coal-field, gives a result considerably in excess of mine, due partly to his having included seams (according to the rule laid down for the guidance of the Commissioners) as thin as one foot in thickness, and also the mountain mines. While adopting Mr. Dickinson's estimate, I must, at the same time, express my dissent to the largeness of the return on the ground of including the thin seams, and leave the public to draw their own conclusions. The limit of depth adopted both by the Commissioners and by myself was 4,000 feet.

1. Area of the Coal-field, including the Manchester and Burnley districts.	217 square miles.
2. Total thickness of strata with coal .	6,000 feet.
3. Number of workable coals above 2 feet: St. Helens, 13; Wigan, 17; Manchester, 18; giving an average thickness of	62 ,,
4. Available quantity to a depth of 4,000 feet, obtained by deducting 181,000,000 tons as the output during the last 10 years . .	5,165,000,000 tons.†

* "Coal-fields," 2nd edit., p. 135.

† Mr. Dickinson's estimate after deducting 200,000,000 tons due to the Cheshire coal-field.—Report, vol. i., pp. ix. and 18.

THE MANCHESTER COAL-FIELD.

The north-eastern side and suburbs of Manchester stand upon a small coal-field, entirely enclosed by New Red Sandstone, except at Collyhurst, where it is in contact with Permian strata. The shape of this coal-field is oblong, with its longest diameter lying N.N.W., it is about four and a half miles in length; and in its broadest part it is about a mile and a half across.

South of the fault which crosses it north of Miles Platting, and on the north side brings in the Permian beds of Collyhurst, the dip of the strata is south-west. The highest beds consist of red clays, shales, sandstones, and six beds of limestone, containing *Spirorbis* and fish; two thin coal-seams, and a bed of black-band ironstone containing in great abundance *Anthracosia Phillipsii*, and scales of fish. Mr. Binney considers this to be identical in position with the black-band ironstone of the Upper Coal-measures of Stoke, Staffordshire. These strata can be traced along the banks of the river Medlock, at Ardwick. The fossils which they contain have already been described (p. 210). Beyond question this is the finest representative series of Upper

Coal-measures in the whole of Britain. Below these calcareous beds there occurs a thick series of shales, sandstones, etc., with seven beds of coal, the thickest of which is only four feet. One of these coal-seams is probably on a parallel with the Worsley "four-feet" mine and its associated strata; but the thick coals, which lie about 1,000 feet below this coal at Pendleton, have not yet been reached in the Manchester coal-field, the intervening strata having apparently thickened out to a great, but unknown, extent.*

Amongst these strata is a bed of calcareous hæmatite which Mr. Binney considers identical with a band of a similar mineral formerly worked at Patricroft Colliery.†

* From a calculation I made some years since, I came to the conclusion that no important coal-seams would be found at a less depth than 616 yards below the Bradford Four-foot coal. See "Geology of Oldham and Manchester," Mem. Geol. Survey, p. 36 (1864).

† "On the Geology of Manchester," Trans. Geol. Soc. Manchester, vol. i.

CHAPTER XIV.

THE BURNLEY COAL-BASIN.*

Lying several miles to the northward of the main coal-field, but united to it by a ridge of high land formed of Lower Coal-measures, stretching from Rochdale by Bacup in a northerly direction, is the small but rich coal-basin of Burnley. This coal-basin sets in along the northern side of a low anticlinal arch, which lies along Rossendale Valley, and which, bringing to the surface the Millstone Grit, separates the Burnley basin from the northern margin of the main coal-field. To the north, the basin is bounded by the Pendle Ridge, which ranges in an E.N.E. direction through Blackburn to Colne, along which the

* A valuable paper on the Burnley Coal-basin was read before the Geological Section of the British Association at Manchester, by Messrs. T. T. Wilkinson, F.R.A.S., and the late Mr. Whitaker, both of whom had devoted much attention to its structure, and the organic remains which its strata present. In my survey of this coal-field in 1867-8, I received much assistance from these gentlemen, and also from the late Sir J. Kay-Shuttleworth, of Gawthorpe Hall.

Millstone Grit and Yoredale beds rise and crop out at high angles; the dip, however, rapidly lessens on receding from the base of the ridge. Along the east, the boundary of the basin is generally a fault, beyond which the moorlands of Yorkshire, formed of different members of the Millstone and Yoredale beds, rise to considerable elevations. One of these faults ranges along the Portsmouth Valley, along which the Millstone Grit is brought up on the south side for a long distance, forming a noble, and often precipitous, escarpment. Another fault, parallel with this, ranges through Townley Park, and between them there is a trough, in which the highest coal-seams of the basin are found. In the centre of the basin is situated the town of Burnley itself, under which the strata are nearly horizontal.

A transverse section taken across the ridges of Padiham Heights and Pendle Hill, in the direction of Clitheroe, gives in unbroken succession a complete series of beds from the *Fulledge main coal*, or Arley mine, to the Carboniferous Limestone; and I believe it is the only spot in Lancashire where none of the links in this chain of rocks are absent, or unbroken.

This section includes :—1. The outcrop of the

"Arley mine," under Padiham reservoir; 2. The Lower Coal-measures, or Gannister beds, with thin coal-seams; 3. The "Rough Rock" and the beds of the Millstone Grit series; and 4. The Yoredale series, forming the western portions of the Pendle Range, passing downwards into massive encrinital limestone. The whole of this series reaches a thickness probably little short of 10,000 feet.

Thickness of the Carboniferous series.—Nowhere in the north of England has the Carboniferous formation from the Mountain Limestone upwards attained such proportions in vertical dimensions as in this part of North Lancashire. The upper portion of the coal-formation has been denuded and lost; but, restoring it to its original dimensions as it occurs in South Lancashire, there appears to have been deposited a total thickness of over 18,000 feet of Upper and Middle Carboniferous Rocks, as determined by several measurements across the Pendle Ridge, which are as follows:*—

* E. Hull "On the Thickness of the Carboniferous Rocks of the Pendle Range of Hills," etc., Journ. Geol. Soc. Lond., vol. xxiv., p. 319. In the measurement of some of these rocks I was assisted by my colleague, Mr. Tiddeman of the Geological Survey.

	Feet.
Upper Coal-measures (restored, as at Ardwick) .	2,013
Middle ,, (partly restored) . .	4,247
Lower ,, (from the Arley mine to the first Millstone or "Rough Rock" .	2,200
Millstone Grit Series of Pendle.	5,500
Yoredale Series of Pendle	4,675
Total	18,635

Succession of Coal-seams at Burnley.

		Thickness. Feet.
	Strata	30
1.	*Doghole Coal*	6
	Strata	21
2.	*Kershaw Coal*	3
	Strata	81
3.	*Shell Coal* (Anthracosia) . . .	2½
	Strata	18
4.	*Main Coal*	5
	Strata	33
5.	*Maiden Coal*	3
	Strata, with 8 thin coal-seams (*Anthracosia rugosa*)	162
6.	*Lower Yard*, or *Five-feet Coal* (with shales	5
	Strata	21
7.	*Lower Bottom Coal*, or *Four-feet Coal* .	3½
	Strata	78
8.	Impure Cannel	2¼
	Strata	21
9.	*Thin Coal* and "fish-bed" . . .	2¾
	Strata	66
10	*Great Mine* { Coal, 28 inches; Shale, 12 ,,; Coal, 19 ,, } .	4 (coal)

		Thickness. Feet.
	Strata	201
11.	*China Bed*	2
	Strata	99
12.	*Dandy Bed*	2
	Strata	141
13.	*Fulledge Main Coal*, or *Arley Mine*	4
	Lower Coal-measures, with Gannister coal, and two or three other seams, with roofs containing Goniatites, Aviculo-pecten, etc.	
	Millstone Grit series, with several thin coals.	

From this section it will be seen that, near the centre of the basin, there are 1,017 feet of strata, down to the lowest thick coal, representing the *Arley mine* of Wigan, or the *Royley mine* of Oldham.

At Gawthorpe we find the following section:—

	Ft.	In.
Various strata	43	2
Coal	1	8
Various strata	57	1
Four-feet Coal	4	3
Various strata, with hard sandstone 24 feet thick	130	0
Yard Coal	3	0
Bing (clay)	9	7
Great, or *Bing Mine* (with parting)	6	0
	254	9

Below these are the Arley and Gannister coals.

The Lower Coal-measures which encircle the basin contain the "mountain mines," which are

here of more than usual importance. The Upper Mountain Mine is about two feet or more in thickness, and the Lower, or "Gannister Coal," has generally a thickness of four feet. The presence of such seams below the Arley mine adds largely to the resources of this basin. Bands of ironstone also occur, and have once been worked in this district.*

Resources.—The estimates of the resources of the Burnley basin are included with those of South Lancashire.†

In 1867 I made very careful estimates of the resources of the Burnley basin for the Geological Survey, of which the following is an abstract:—

Low Bottom Mine	7,000,000	tons.
Fulledge Thin Mine	5,000,000	,,
Great Mine	12,000,000	,,
Arley Mine	65,000,000	,,
Gannister Mine	100,000,000	,,
Total	189,000,000	tons.

The remaining seams were not included in the estimates, having been either worked out, or being unimportant.

* Mr. E. W. Binney, Mem. Lit. and Phil. Soc., Manchester, vol. xii.

† I was informed by the late Sir J. Kay-Shuttleworth that coal is known to have been worked at Burnley in the reign of Henry VIII.

The quantity of coal raised in Lancashire in 1878 was 18,676,600 tons from 565 collieries; an increase of 4,681,100 tons on the output of 1869. Lancashire contains the deepest coal-mines in the British Isles, that of Rose Bridge, near Wigan, 806 yards in depth, and that of Dukinfield, in Cheshire, on the confines of Lancashire, 717 yards; while there are several shafts varying from 400 to 600 yards in depth in the western part of the coal-field. Several large firms also raise from their own pits nearly one million of tons of coal yearly. In this district mining operations are conducted on a large scale, and with the most perfect mechanical appliances.

CHAPTER XV.

PARK GATE COAL-FIELD, CHESHIRE.

A NARROW band of dark colour on our geological maps, stretching for upwards of a mile along the eastern shore of the estuary of the Dee, marks the position of the Park Gate Coal-field. From its position with reference to the coal-field on the opposite shore, we can scarcely doubt but that it is connected with the Flintshire coal-field under the sea; and the coals have actually been worked seawards for some distance. The general dip of the coal-strata is southwards and westwards; and inland they are separated from the New Red Sandstone by a large fault which enters the sea at the north side of Burton Point, where a very interesting section of this latter formation is exhibited in the cliffs. The following is a section of the coal-series, for which I am indebted to my friend Mr. P. Higson, of Manchester :—

Section of the Coal-series, Park Gate.

	Yds.	Ft.	In.
Strata	23	0	5
Coal	0	2	0
Strata	3	0	7
Coal (Main-seam) . . .	1	2	8
Strata	14	0	0
Coal	1	1	0

It has been suggested that these seams correspond with the "Brassy," "Main," and "Lower Fourfoot" coals of Flintshire.

CHAPTER XVI.

INGLETON AND BURTON COAL-FIELD, NORTH LANCASHIRE.

This is a small coal-field, lying a short distance to the south of Kirkby Lonsdale, and to the E.N.E. of Lancaster.* Its relations to the surrounding rocks and its own structure are obscure, owing to the deposit of Drift clay and gravel by which it is overspread.

Along the north-east it is bounded by the "Great Craven Fault," which brings up the Lower Carboniferous Rocks; in the other directions it reposes on beds of Millstone Grit and Yoredale series, and is partially overlaid by red sandstones and breccias, which are laid open in the valley of the Lune, and referred by the

* It has been described by the late Professor Phillips, in his "Geology of Yorkshire," and more recently by Mr. Tiddeman, of the Geological Survey, in a communication to Professor Ramsay, which is inserted in his report "On the Possibility of finding Coal under the newer Formations," etc.—Rep. Coal-Commission, vol. i., p. 127.

Geological Surveyors to the Permian formation.* The beds of coal have hitherto only been worked on a small scale.

The following is a section of the Coal-series as given by Professor Phillips, from the notes of Mr. Hodgson, mining engineer :—

	Ft.	In.
Measures	82	0
Coal	1	0
Measures	31	0
Coal	1	0
Measures	4	0
Main, or *Four-foot Coal*	4	0
Measures	4	0
Coal	2	0
Measures	28	0
Crow Coal	1	8
Measures	54	0
Deep Coal	6 ft. to 9	0
Measures	3	0
Coal	2	0
Measures	80	0
Coal	2	0
Potter's Clay	4	0

* Geol. Survey Map, Sheet 98, S.E.

CHAPTER XVII.

CUMBERLAND COAL-FIELD.

THE zone of Carboniferous rocks which wraps round the northern flanks of the Cumberland mountains is surmounted by the rich coal-field of Whitehaven, Workington, and Maryport. Between this last town on the north and St. Bees' Head on the south, it stretches along the coast of the Irish Sea, and extends inwards for a distance of five miles, in which direction the beds rise and crop out. From Maryport the coal-field extends eastward to Bolton. Its total length is about 20 miles, and greatest width, at Workington, about 5 miles.*

From the Memoir of Professor Sedgwick, who has recorded the distinctive features of this coal-field, I gather the following descending series.†

* Ruthven's Geological Map of the English Lakes.

† Trans. Geol. Soc. of London, vol. iv. Brit. Assoc. Report, vol. vi., p. 75 (1837). I have also been kindly assisted by Mr. Dickson, of Whitehaven, who has furnished several colliery sections and much general information.

Succession of Strata.

Permian Strata.—1. Sandstones of St. Bees' Head, decomposing into grotesque and castellated forms.

2. Gypseous marls, surmounted by sandy marls and micaceous sandstone.

3. Conglomerate of magnesian limestone, etc., resting on an eroded surface of the Whitehaven sandstone.

Coal-measures 2,000 feet. } 1. (?) Massive reddish sandstone of Whitehaven. Professor Sedgwick appears doubtful of the affinities of this rock—100 to 150 feet.*

2. *Middle*, most fully developed at Cleat Moor, containing 7 workable coal-seams.

3. *The Lower*, with 4 or 5 thin and inferior coal-seams.

1. Grits and limestone shales, with thin bands of coal at Hesket New Market. The limestone at Cleator and Wath, very rich in hæmatite iron-ore.

Succession of the Coal-seams.
Whitehaven.

		Thickness. Feet.
	Strata	432
1.	*Yard Band* (about)	3
	Strata	30
2.	*Coal*	$2\frac{1}{2}$
	Strata, with a coal-seam	78
3.	*Bannock Band*	8 to 9
	Strata	60
4.	*Main Band*	6 to 11
	Strata	240
5.	*Low Bottom Coal*	4

* After a personal inspection of this sandstone, I feel no doubt of its belonging to the Coal-measures.

Workington.

	Thickness. Feet.
Strata	132
1. *Fiery Band*	2
Strata	96
2. *Brassy Band*	$2\frac{1}{4}$
Strata	72
3. *Cannel*, or *Metal Band*	4 to 6
Strata	60
4. *Bannock Band*	$5\frac{1}{2}$
Strata	30
5. *Little Main Band*	3 to 4
Strata	180
6. *Main Band*	9 to 10
Strata	210
7. *Yard Coal*	2 to 3
Strata	102
8. *Four-feet Coal*	4
Strata	150
9. *Udale Band*	3 to 4

At Maryport, beneath the Lower Red Sandstone, there occurs the "Ten-quarter coal," 7 feet thick, supposed to represent the "Bannock Band" of Workington, and the "Metal" and "Cannel bands," separated by 36 feet of strata, are considered to represent the "Main band."

The thick coals of Workington are thrown out south of that town by a large fault, upheaving the Lower Coal-measures, which occupy an extensive plateau, stretching from Harrington to the hills north of Moresby. Another great fault,

with a downthrow on the south-west, again brings in the productive measures of Whitehaven. Unfortunately, however, between this fault and the village of Parton, the beds dip to the east, so that all the coal-seams below high-water mark crop out under the sea, and the coal cannot be extracted on account of the quantity of sea-water which finds its way along the planes of bedding. In one of the collieries at Whitehaven, however, the coal has been followed 3,200 yards under the sea.*

From Workington to Flimby, a large unwrought coal-field is supposed to exist, and from Workington to Maryport the general dip of the strata is north-west, and the coals crop out inland, where they have been worked to some extent in very early times.

From Maryport to Bolton, by Crosby and Aspatria, the coal-seams are overlaid by the newer strata of Permian age, under which they probably extend for some undefined distance, which Professor Ramsay considers may reach as far eastward as Carlisle †—and northward, so as to join the little coal-field of Canobie, which, according to the report of Professor

* As I am informed by Mr. W. W. Smyth, F.R.S.

† Report of Coal-Commission, vol. i., p. 140.

Geikie, contains eight seams of coal, having an aggregate thickness of 42 feet.*

Resources.

The estimates of the quantity of available coal made by Mr. T. E. Forster largely exceed those made by myself, partly arising from seams of coal under two feet in thickness having been excluded from my estimate, as being too thin for working at great depths. Mr. Forster also includes the seams of coal extending for a distance of two miles out to sea, which adds one-third to the quantity under the land. I here substitute Mr. Forster's estimate for my own, after deducting eight millions of tons for the quantity under 18 inches in thickness: †—

1. Area of Middle Coal-measures . .	25 square miles.
2. Average thickness of workable coal .	35 feet.
3. Available quantity of Coal, after necessary deductions for loss, etc., on land, 300 millions of tons . .	400 millions of tons.
4. Available quantity under the sea, 100 millions of tons . . .	

In the year 1878 there were 31 collieries,

* Report of Coal-Commission, vol. i., p. 168.

† *Ibid*, 21. I have made the necessary reduction for the quantity (in round numbers) worked out during the last 10 years.

from which were raised 1,388,233 tons of coal, of which 495,999 tons were shipped to ports of the United Kingdom, Dublin being the principal.* The output has increased during the last twenty years, it having amounted to only 1,041,890 in 1859.†

* "Mineral Statistics," 1878, p. 109.
† *Ibid*, 1859.

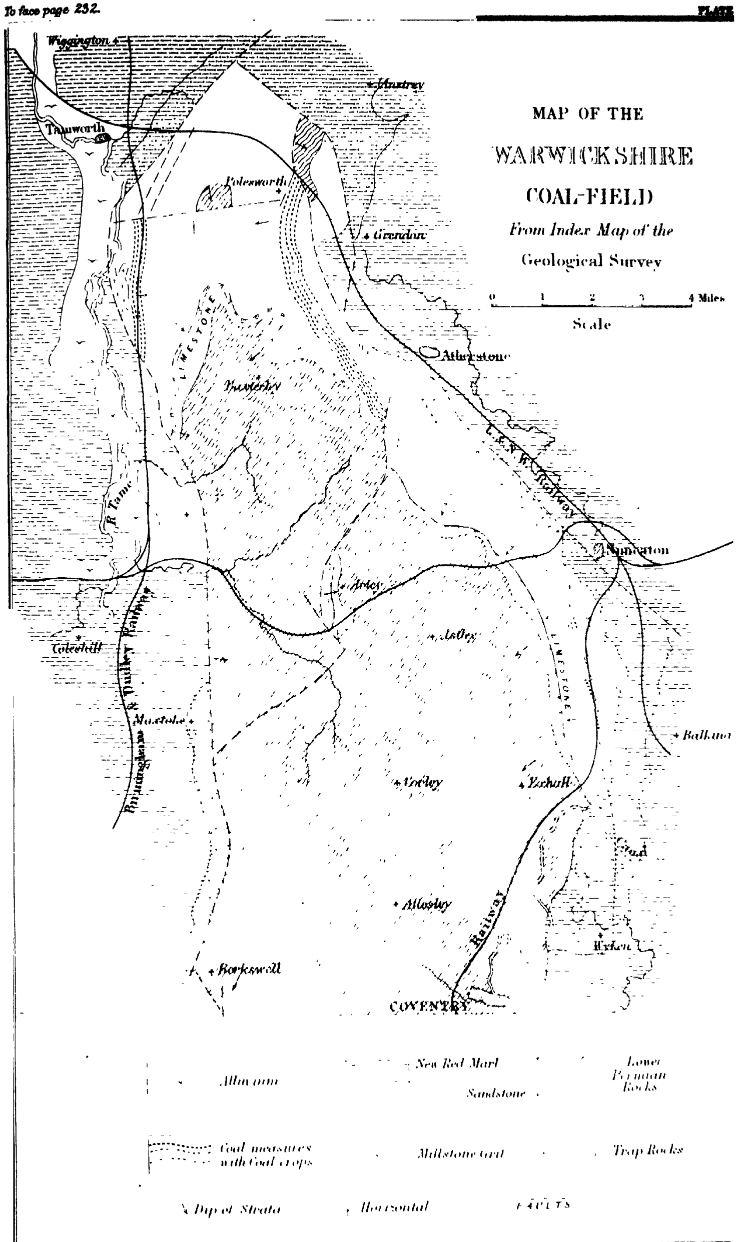
CHAPTER XVIII.

WARWICKSHIRE COAL-FIELD.*

THIS is the nearest to the metropolis of all the coal-fields. It extends towards the south-south-east of Tamworth, in a constantly narrowing band, by Atherston and Nuneaton, to near Wyken — a distance of 15 miles. At the northern end the strata form a trough four miles in breadth, bounded on the west, north, and east by faults which bring in the New Red Sandstone. The Coal-measures dip under a large district occupied by Lower Permian rocks, extending under Coventry and Warwick. This tract, with an area of 90 square miles, is underlaid by coal at a depth probably not greater than 2,500 feet in any part, often much less. At the

* For details of this coal-field see Mr. Howell's Memoir "On the Geology of the Warwickshire Coal-field, etc.," and the Maps and Sections of the Geological Survey. The section of the coal-field is reduced from No. 5, Sheet 51, by Mr. Howell.

To face page 232.



Stanford's Geog Est

south end of the coal-field the whole of the Coal-measures are overlapped by the New Red Sandstone, which passes across the edges of the beds and rests upon the Permian rocks. The prolongation of the coal-seams under the Trias has been proved as far south as Wyken Colliery, about two miles E.N.E. of Coventry. How much farther south they may extend it is impossible to say; but the probabilities are, that at some distance in the same direction the coal-seams will be found to terminate against the same bank of Silurian rocks, which forms the southern limit to the coal-seams of South Staffordshire.*

SOUTH-WEST.

NORTH-EAST.

Fig. 14.—SECTION ACROSS THE CENTRE OF THE WARWICKSHIRE COAL-FIELD.

Length about 6 miles.

At Arley occurs the outcrop of Limestone with *Spirorbis*.

* This is the view expressed by Professor Ramsay, F.R.S., in his Report on the "Probability of finding Coal under the Permian and N. R. Sandstone."—Rep. Coal-Commission, vol. i., p. 129.

General Succession of the Formations.

		Maximum Thickness Feet
Trias.	1. Red Marl	600
	2. Lower Keuper Sandstone . . .	180
	3. Bunter Sandstone, only sparingly represented towards the north.	
Lower Permian Rocks.	1. Brown and purple sandstone and marl, with calcareous breccia and conglomerate, with *Strophalosia?* *Labyrinthodon*, and plants . .	2,000
Coal-measures.	1. Sandstones and shales, at the base of which is a band of limestone, with *Spirorbis carbonarius* . . .	50
	2. Coal-measures, with five workable coals lying near the centre of the series	1,400
	3. Lower Coal-measures unproductive of coal, and traversed by sheets of basalt	1,500
Millstone Grit.	1. Hard siliceous rock, with bands of shale, altered by intrusive trap (about)	500

Coal-seams.—The five workable coals lie about 600 feet below the "*Spirorbis* limestone." At the northern end of the district they are separated by about 120 feet of shales and sandstones, which all decrease in thickness southwards, while the coals remain nearly the same; and at Wyken, near Coventry, the five seams combine

to form one bed 26 feet in thickness. This is a change parallel to that which occurs in South Staffordshire in the case of the *thick coal*, which becomes split up northwards from Wolverhampton. Both cases exemplify in a remarkable degree the greater persistency of coal-beds over the sedimentary strata with which they are associated.

Under the Permian rocks there is about an equal quantity of coal at a depth of less than 2,500 feet, and about four times as much under 4,000 feet. Mr. Howell's sections show the probability that the coal-seams lie very regularly, and nearly horizontally under this formation. I cannot, therefore, but regard as of peculiar value this vast reservoir of fuel lying at the borders of the south-eastern counties, and actually closer than any other coal-bearing district to the metropolis of Britain.

The Lower Coal-measures are traversed by several intrusive sheets of diorite,* which *nearly* correspond with the planes of bedding. These dykes have been injected subsequently to the

* These rocks have been microscopically examined by Mr. S. Allport, who finds them to be "ordinary diorites," hornblende being the prevalent pyroxenic mineral, while augite, olivine, etc., are also present.—Q. J. G. S., November 1879.

deposition of the Coal-measures, as they have baked and blanched the shales with which they are in contact. At the base of these strata we find the Millstone Grit changed into a kind of quartzite through the influence of a mass of greenstone upon which it rests. Beyond this the whole of the strata are broken off by a great fault, which introduces the Trias to the eastward.

Resources.

The investigation into the resources of the Warwickshire coal-field was entrusted to the late Mr. J. T. Woodhouse, F.G.S., one of the Commissioners, whose estimate I here substitute for my own, which it somewhat exceeds; the difference, however, not being very material:*—

1. Area of Coal-field (between the boundary of the Permian formation and the outcrop of the "7-foot" coal) .	30 square miles.
2. Thickness of Coal . .	from 26 to 30 feet.
3. Tonnage remaining unworked (Woodhouse)	809,730,113 tons.
4. Net available tonnage in 1870 (W.) .	455,473,182 ,,
5. Do. in 1880 (about) .	445,000,000 ,,

The quantity of coal raised in 1878 was 1,025,450

* The depth is under 3,000 feet for the whole quantity.—Report Coal-Commission, vol. i., p. 31.

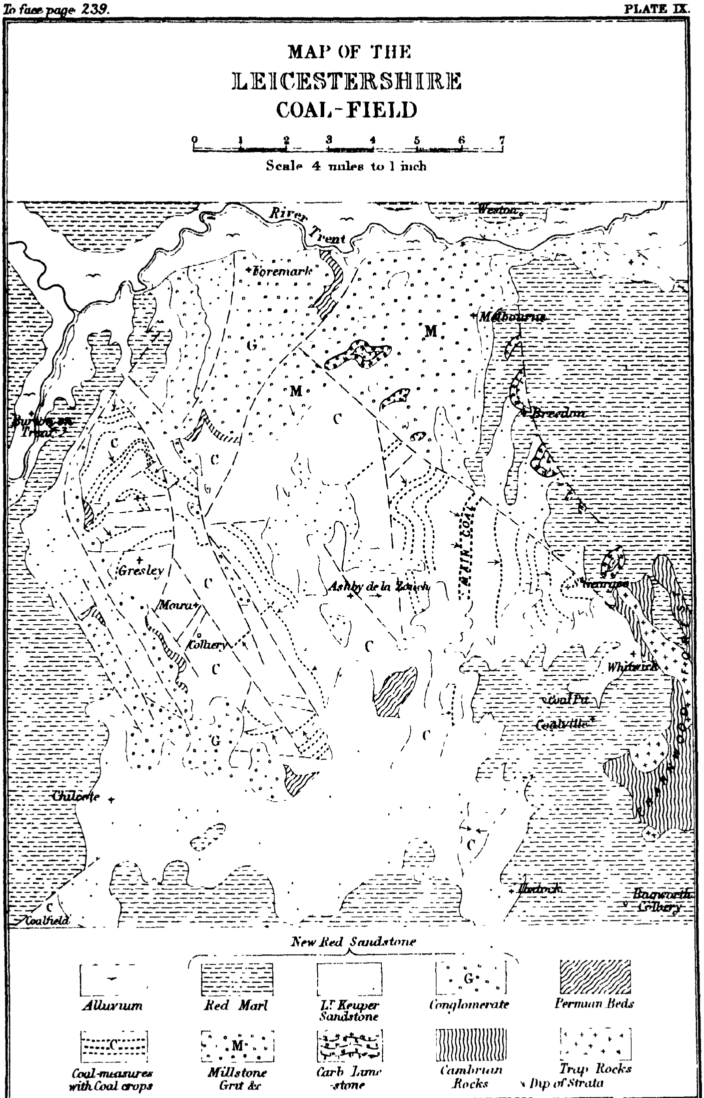
tons from 34 collieries. It seems strange that the quantity should be so small considering the advantageous position which the collieries occupy with reference to the London and central markets. In 1870 the quantity was 647,540 tons, showing since then considerable progress.

CHAPTER XIX.

THE LEICESTERSHIRE COAL-FIELD.*

THIS small but valuable coal-field occupies an irregularly-shaped district south of the Valley of the Trent. Along its western, northern, and southern sides, it is bounded by strata of the age of the New Red Sandstone; and along the north-east, by the ancient slates and porphyries of Charnwood Forest, which form a miniature mountain range, rising in rugged knolls and serried ridges above the general level of the country. The Coal-measures underlie the New Red Sandstone to a large and unknown distance towards the south and west; and in the Coleorton district, several collieries are situated upon

* This coal-field has been very ably illustrated by Mr. Mammatt, in his "Geological Facts," and more recently by the works of the Geological Survey, consisting of Map 63, N.W., 71, S.W.; Horizontal and Vertical Sections; and a Memoir "On the Geology of the Leicestershire Coal-field," by the Author, 1860. The late Rev. W. H. Coleman has also largely contributed to the knowledge of a district of peculiar geological interest.



Stanford's Geog! Estab! London.

London: Edward Stanford, 55, Charing Cross.

the Keuper Red Marl, and pierce this formation downwards to the coal beneath; the deepest of these shafts is at Bagworth colliery.

The coal-field is physically divisible into three districts—that of Moira, on the west; Ashby-de-la-Zouch, in the centre; and Coleorton, on the east. The central district is formed of Lower Coal-measures, without workable coals, and is bounded on both sides by down-cast faults, which introduce the workable coal-beds of Moira and Coleorton. The coal-series of these latter districts cannot be identified with each other, though they are probably synchronous. "The main-coal" of Moira is from twelve to fourteen feet thick; that of Coleorton, from six to eight feet.

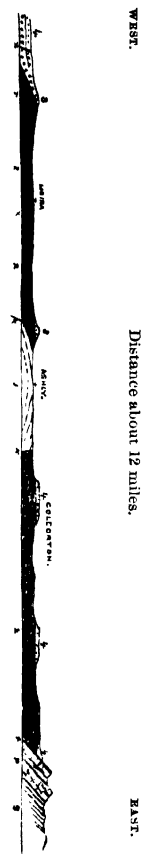


Fig. 15.—SECTION ACROSS THE LEICESTERSHIRE COAL-FIELD.
Distance about 12 miles.

4. Keuper Sandstone and Marl. 3. New Red Conglomerate. 2. Middle Coal-measures, with coal. 1. Lower Coal-measures. X Faults. P. Porphyry. S. Slate. } Cambrian Rocks of Charnwood Forest.

General Succession of Formation—Leicestershire.

Trias . . .	Keuper series	700 feet.
	Bunter (sometimes absent). .	200 ,,

Permian Rocks:	Breccia, sparingly represented.	
Carboniferous Series.	1. Upper Sandstone (unconformable).	
	2. Middle Coal-Measures, with about 20 coal-seams, of which 10 are workable .	1,500 ,,
	3. Lower Coal-measures, unproductive	1,000 ,,
	4. Millstone Grit . . .	50 ,,
	5. Yoredale series and Carboniferous Limestone.	

The following is a list of the coal-seams in both the Moira and Coleorton districts:—

Coal-seams of the Leicestershire Coal-Field.

Moira District—(West.)	Ft.	In.	Coleorton District—(East.)	Ft.	In.
Ell Coal (*b*)	3	8	Stone smut (*c*)	4	9
Dicky Gobbler (*b*) ...	3	6	Swannington (*a*)	3	7
Block Coal (*a*)	3	6	Slate-coal (*b*)	4	8
Little or Four-feet (*a*) ...	4	6	Coal...	2	10
Cannel (*b*)...	3	6	Coal	3	7
Main { Over Seam / Nether Seam } ...	12	0	Main-coal (*a*)	6	0
			Upper Lount (*b*)	3	9
Toad (*c*)	3	6	Second Lount (*b*)... ...	3	0
Little Woodfield (*c*) ...	2	6	Middle Lount	4	6
Woodfield (*b*)	5	0	Nether Lount	4	6
Stockings (*c*)	9	0	Heath End Coal and Cannel	10	0
Eureka (*a*)...	4	6	Lower Coal-measures.		
Strata below this unproved.					

In the above list, I have omitted several of the least important coals. The letters *a*, *b*, *c*, indicate the degrees of quality.

I shall conclude this account of the Leicestershire coal-field by stating a few geological facts of interest.

Igneous Rocks.—At Whitwick, a remarkable

sheet of dolerite or melaphyre, locally called "whinstone," intervenes between the Coal-measures and the New Red Sandstone.* In one of the shafts of Whitwick colliery it is 60 feet thick, and has turned to cinders a seam of coal with which it comes in contact. It has evidently been poured out as a sheet of lava over the denuded surface of the Coal-measures at some period prior to that of the Trias,† and from a vent, probably situated at the junction of the Coal-measures with the old rocks of Charnwood Forest. The mutual relations of these rocks I have endeavoured to

* This rock has been microscopically examined by Mr. S. Allport, F.G.S., who finds it to be composed of triclinic felspar (probably Labradorite), augite, titano-ferrite, and olivine.—*Geol. Mag.*, vol. vii., p. 160 (1870). It is therefore an old dolerite or melaphyre, of later date than the Coal-measures on which it rests unconformably, and older than the New Red Sandstone (or at least than the Keuper), and therefore referable, in all probability, to some part of the Permian period.

† George Stephenson, the inventor of the locomotive engine, under whose direction the Whitwick shafts were sunk, had the sagacity to perceive that neither this layer of whinstone, nor yet the Triassic sandstones and marls which overlie it, interfered with the existence of coal beneath; so that, to all the doubts that were suggested during the progress of the works, he only returned the answer, "persevere." At length the shaft passed through the whinstone, and the Coal-measures were reached beneath, greatly to the astonishment of all beholders.

illustrate in the Geological Survey Memoir of this district.*

Rock-Faults.—In the same district, the main-coal has been extensively invaded by channels filled up with fine sand, which completely replace the coal over several hundred yards. One of these banks of sandstone, at Pegs-green colliery, was found to be 80 yards in width. It is composed of the same sandstone that forms the roof of the coal itself. In another of these, south of Whitwick colliery, a tunnel was driven to a distance of 110 yards without passing through it. These phenomena are similar to those already described in the case of the coal-field of the Forest of Dean.

Salt-water.—In the main-coal of Moira, especially in the Bath colliery, at a depth of 593 feet, salt-water, beautifully clear and of nearly the same composition as sea-water, trickles down from the fissures where the coal is being extracted. The brine is carried to Ashby-de-la-Zouch in tanks, and is considered highly beneficial in scorbutic and rheumatic affections.

Resources.

The estimates of the resources of this coal-

* Geology of the Leicestershire Coal-field, Fig. 8, p. 45.

field, furnished by the Royal Coal-Commission, were entrusted to the able hands of the late Mr. J. T. Woodhouse, and are here substituted for those originally made by myself, of which they are largely in excess. This is partly owing to seams of "12 inches and upwards" being included, as also the quantities of coal proved to exist by working under the Permian and, I presume, Triassic formations.*

1. Area of productive coal-field . .	15 square miles.
2. Number of workable coals from 2 feet upwards in thickness, 10 with a total thickness of coal, from 40 to . .	45 feet.
3. Moira district, available quantity for future use, all necessary deductions having been made.	454,161,946 tons.
4. Coleorton district, do., 382,637,788.	
5. Total available quantity in 1880 (about)	836,800,000 tons.

According to the returns prepared by Mr. T. Evans, there were raised in 1878 from 28 collieries 1,020,500 tons of coal. In 1870 the quantity was 599,450 tons.

Fossils.—The plant remains are abundant, and have been figured in Mammatt's "Geological Facts." *Goniatites* and other marine forms have been observed in the Lower Coal-measures. Mr. W. Molyneux describes the occurrence of

* Rep. Coal Commission, vol. i., p. 30.

Orthoceras, *Goniatites Listeri*, *Aviculo-pecten*, *Posidonia*, and *Lingula*, in the shale roof of the "Main Coal," where it was reached in a shaft below the New Red Sandstone and Permian beds beyond the limits of the coal-field near Overseal. He also points to the apparent connection of these forms with the occurrence of salt water in the "Main Coal" itself, which he believes to be that of the original sea—locked up in the rock between two layers of impervious clay, one above, the other underneath the coal.*

Shells of the genus *Anthracosia* are not uncommon, and a species of *Leperditia*, (*L. arcuata* Bean.) has been noticed by Professor A. H. Green.

* Rep. Brit. Assoc. 1877, p. 73.

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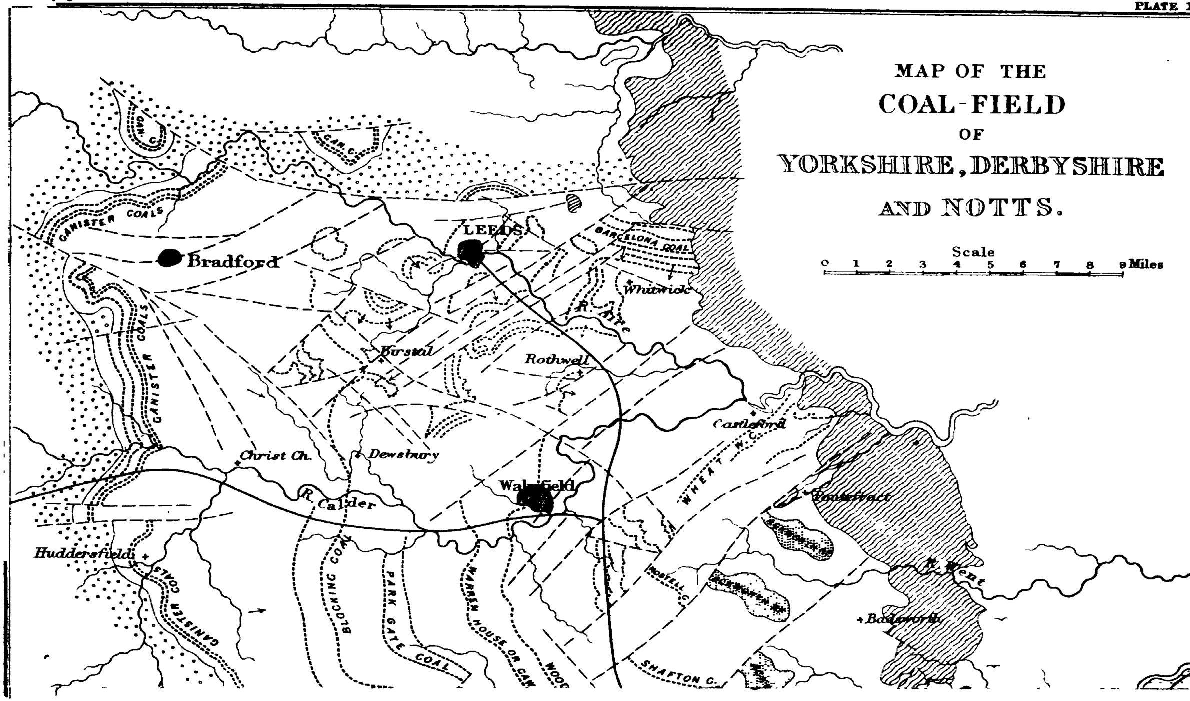
PLATE X.



CHAPTER XX.

NOTTS, DERBYSHIRE, AND YORKSHIRE COAL-FIELD. (MIDLAND.)

THIS great field, though forming parts of the shires of Derby, Nottingham, and York, is physically *one;* and in treating of its structure and resources we must ignore political and social landmarks. It is the largest coal-field in England; and about 150 square miles smaller in area than that of South Wales.

Its eastern margin is defined by the escarpment of the Magnesian Limestone, with its subordinate Lower Permian Sandstone, which, commencing near Nottingham, extends northwards beyond the limits of the coal-field itself.*

* On approaching the valley of the Trent the Permian beds become attenuated and debased; the Magnesian Limestone passes into a yellow calcareous sandstone, and the Lower Sandstone is but feebly, if at all, represented. All this is in consequence of the near approach of the formation to its original margin, formed by the uprising of the Lower Carboniferous, and still older, rocks of Charnwood Forest, above the sea level of the period.

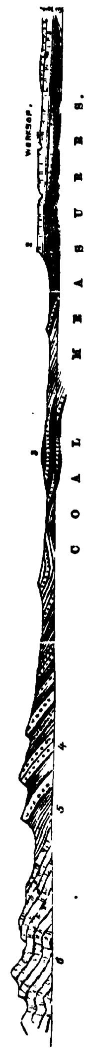


Fig. 16.—GENERAL SECTION ACROSS THE DERBYSHIRE AND YORKSHIRE COAL-FIELD. Drawn along the border of the two counties into Notts. Distance 25 miles.

Upon reaching the crest of the escarpment, you find yourself on the edge of a table-land, resembling that of the Oolite Limestone of Gloucestershire, but less lofty. One prominence of this ridge is crowned by the turrets of Bolsover Castle. The southern boundary is of New Red Sandstone, and the strata rise and crop out westward as far north as Bradford and Leeds, where they bend round to the east, and finally disappear under the Magnesian Limestone, which passes over and rests directly on the Millstone Grit. The greatest length of the coal-field from south to north is 66 miles; and its breadth varies from five to twenty miles. Though the general dip of the strata is eastward, there generally occurs along the centre of the field a gentle undulation (shown in the section, Fig. 16), which for a certain distance produces a

westerly dip; but in Derbyshire the strata generally roll over when approaching the base of the Permian Rocks. In Yorkshire, their relations are variable. The coal-seams are only occasionally broken by faults except towards the N.W. margin.

To the westward, the Lower Carboniferous series rises into the lofty ranges of the Pennine chain, forming a natural division between the counties of Stafford and Lancaster on the west, and Nottingham and York on the east, as well as for their respective coal-fields. In fact, the upheaval of the Lower Carboniferous rocks, and the supervening denudation, has rent asunder a coal-field which originally embraced the whole of that portion of the North of England extending from the coast of Lancashire and Cheshire across to an undefined margin, which probably corresponded pretty nearly with the line of the river Trent, or even stretched farther eastward.

The loftiest escarpment of this central chain is Mickle Fell, formed of Millstone Grit, which reaches an elevation of 2,600 feet; the table-land of Kinder Scout, in the district of the High Peak, lying in the centre of the great arch of Millstone Grit, between the Cheshire and Derbyshire coal districts, is about 2,000 feet;* and in one place

* See "Geology of Stockport," etc., Mem. Geol. Survey, p. 12.

the Carboniferous Limestone of Derbyshire rises 1,533 feet above the sea.

Historical Notices.—This great coal-field and its bordering formations have been the subject of several important notices bearing on their mineral structure. As far back as 1684, Lister, whose name has been immortalized by Phillips in the well-known fossil *Goniatites Listeri*, proposed to the Royal Society the construction of geological maps, and illustrated his views by reference to the formations of Yorkshire, and the divisions he would have pourtrayed.* After him (1778) Whitehurst published some good sections of Derbyshire.† A few years later the Board of Agriculture, with the assistance chiefly of Mr. W. Smith, published a series of geological maps embracing parts of Yorkshire, Derbyshire, and Notts; and shortly after the commencement of the present century, Mr. Farey produced his well-known report on the mineralogy of Derbyshire. With the publication of William Smith's Geological Map of England, in 1815, we enter upon the modern epoch of our science, which has been enriched, as far as regards the region we are now

* Philosophical Transactions, 1684.

† In the work entitled "Inquiry into the original state and formation of the Earth," by John Whitehurst.

investigating, by the labours of Phillips,* Sedgwick,† and Binney.‡ The Government Geological Surveyors have also just completed the detailed survey of this coal-field; and have produced an elaborate memoir on the Geology of the Yorkshire coal-field.§

Succession of Strata.

Southern Extremity—Derbyshire and Notts.

The succession of strata along a line drawn from Kirkby Woodhouse through Alfreton Common and Wingfield Manor to Crich, may be very clearly ascertained, both from the details of the collieries, and the natural sections which present themselves. The following is the series in descending order: ||—

		Feet.
Permian Rocks.	1. Marls and sandstone . .	40
	2. Magnesian limestone (lower bed)	60
	3. Marls and sandstone . .	30

* "Geology of Yorkshire."

† Papers published in the Transactions of the Geological Society of London (1826).

‡ Papers published in the Lit. and Phil. Soc., Manchester, etc. Another work requiring notice is Mr. Denny's "Fossils of the Yorkshire Coal-field," Proc. Geol. Soc., York., vol. ii.

§ "The Geology of the Yorkshire Coal-field," by Professor A. H. Green, Mr. Russell, and several assistants (1878).

|| Horizontal Sections of the Geological Survey, Sheet 60.

		Feet.
Middle Coal-measures, 2,500 ft.	Strata to Top Hard Coal, about .	700
	Waterloo Coal	1,600
	Ell	
	Lower Hard	
	Furnace	
	Black Shale or Clod . . .	
	Kilburn	
	Shales, with Ironstones . .	
Lower Coal-measures, or Gannister series.	Flagstones of Wingfield Manor.	
	Shales and flaggy sandstones, with two coals underlaid by Gannister floors	1,000

The above are underlaid by Millstone Grit and Yoredale beds. These strata, in their extension southwards towards the valley of the Trent from Ambergate, gradually bend round towards the south-east, having a north-easterly dip, with which they pass beneath the New Red Sandstone, under which formation their presence has been recently proved by the opening of a colliery near the bank of the Trent opposite Wilford Church.

In comparing the above series with that on the Lancashire and Cheshire side of the Pennine anticlinal, it is to be remarked, that while there is a general diminution in the total thickness of the strata, they can unquestionably be correlated from the Millstone Grit up into the lower beds of the middle Coal-measures. Thus, the upper-

most Millstone Grit is identical with the "Rough Rock" of Lancashire. The coal-seams of the Lower Coal-measures, and the flagstones of Wingfield Manor, have their representatives in Lancashire; and the Blackshale coal is, with much reason, supposed to be the representative of the Royley, or Arley mine, of the same county.

For the purpose of affording a comparison of the formations towards the north and south of the field, I here select sections from Nottinghamshire, and Barnsley in Yorkshire.

GENERAL SECTION OF STRATA.

Nottinghamshire.*—(Shireoak Colliery.)	Ft.	Barnsley, Yorkshire.†	Ft.
Permian Rocks. Upper Permian marls and sandstone ...	56	Magnesian Limestone ...	75
Permian Rocks. Magnesian limestone ...	102	Lower Permian Sandstone ...	54
Permian Rocks. Lower Permian sands and shale	38	*Red Rock of Rotherham* ...	?
Strata, with beds of hæmatite and ironstone ...	42	Strata ...	0 to 100
The Manor Coal ...	2	*Pontefract Rock* ...	100
Strata, with several thin coals	706	Strata ...	70
Shireoak or *Melton*, or *Baelbro' Hall Coal* ...	4¼	*Ackworth Rock* ...	54
Strata, with an inferior coal, 3/2 thick ...	120	Strata ...	510
Furnace Coal ...	2¾	*Shafton Coal* ...	5
Strata ...	138	Strata, principally sandstone (Chevit rock) ...	393
Hazles Coal ...	3	*Muck Coal* ...	3½
		Strata ...	219
		Woodmoor Coal ...	3
		Strata with half-yard coal ...	45
		Winter Coal ...	4
		Strata	

* Partly taken from section of Shireoak Colliery by Messrs. Lancaster and Wright, Journ. Geol. Soc., vol. xvi., p. 138.

† Rev. W. Thorpe, Section of Strata.—*Ibid.* I need scarcely observe that the thickness of the strata and coals is variable.

GENERAL SECTION OF STRATA—(*Continued*).

Nottinghamshire.—(Shireoak Colliery.)	Ft.	Barnsley, Yorkshire.	Ft.
Strata	238	*Beamshaw Coal*	3
Top Hard Coal (or *Barnsley Coal*	3¾	Strata, with Kent Coal 1 foot, and Maple Coal 4½ feet (inferior quality)	
Strata ... / *Dunshill Coal*, 2¾ / Strata	155	Strata	216
Waterloo Coal	2½	*Barnsley Coal*	9¼
Strata, with 2 coals, two feet each in thickness	345	Strata	198
Soft Coal	3½	*Swallow Wood Coal*	3
Strata	120	Strata	234
Lower Hard Coal	4	*Joan Coal*	2
Strata ... / *Piper Coal*, 2¼ / Strata	200	Strata	60
Furnace Coal	4	*Flocton Top Coal*	3¼
Strata, with Yard Coal ...	360	Strata	120
Clod, or *Black Shale Coal* ...	5—6	*Park Gate Coal*	5
Strata	480	Strata	78
Kilburn Coal	3½—5	*Thorncliffe Thin Coal* ...	2½
Strata (with ironstone) ...	350	Strata	123
		Four-feet Coal (variable) ...	2½
		Strata	108
		Silkstone Coal	5
		Strata	195
		Whinmoor or *Lowmoor Coal*	2½
		Strata ... (about)	150
		Flagstone ... (about)	36
Flagstone overlying the Lower Coal-measures consisting of flagstones, shales, and the coals with Gannister floor, thickness rather uncertain (about)	500	Strata, principally shales ...	495
		Halifax Coal (with *Pecten papyraceus* in the roof), and a floor of Gannister ...	1¾
		Strata (shales and flags) ...	81
		Halifax Soft Coal	1½
		Strata	150
Millstone grit.		Millstone Grit.	

The following is a section of the strata at Cinderhill Colliery, showing their character near the southern extremity of the coal-field: *—

* Mr. W. T. Aveline, "Geology of Nottingham," Mem. Geol. Survey, 1861.

VERTICAL SECTION OF THE NOTTINGHAM AND DERBYSHIRE COAL-FIELD.

The first part (to the Top Hard Coal) from a pit at Cinderhill.

No.	Description of Strata.	Thickness Ft.	Thickness In.	Depth. Ft.	Depth. In.
1	Limestone (Magnesian)	5	4	—	
2	Light-blue and brown stone in beds ...	6	3	11	7
3	Blue-stone	8	5	20	0
4	Dark-pink bind	3	8	23	8
5	Dark-grey stone	0	4	24	0
6	Red stone with pebbles	1	0	25	0
7	Clunch (usually tough clay or shale) ...	1	9	26	9
8	Bind	19	0	45	9
9	Ironstone	0	3	46	0
10	Soft clunch	5	0	51	0
11	Black shale or bind	2	7	53	7
12	Clunch	6	8	60	3
13	Bind, with bands of ironstone	40	4	100	7
14	*Chillery Coal*	0	7	101	2½
15	Light and dark clunch	6	0	107	2½
16	Bind	20	9	127	11½
17	Ironstone	0	2	128	2
18	Bind	14	7	142	9
19	Soft coal	1	2	143	10½
20	Shale bind and clunch	20	2	164	0½
21	*Soft Coal*	2	4	166	5
22	Clunch and bind, with bat and shale ...	18	10	185	
23	Soft Coal	1	0	186	3
24	Clunch and bind	1	0	187	3
25	*Soft Coal*	1	8	188	10½
26	Clunch and stone	9	5	198	3½
27	Bind, clunch, stone, and bat, with a little coal and ironstone	81	8	280	0
28	*Coal*	3	6	283	6½
29	Dark clunch, with bat and ironstone ...	20	8	304	2½
30	Coal	0	7	304	9½
31	Shaly bind	10	1	314	10½
32	*Soft Coal*	2	4	317	2½
33	Shale and bind	36	2	353	4½
34	*Soft Coal*	3	4	356	8
35	Dark clunch, with impressions	3	11	360	7½
36	*Soft Coal*	1	3	361	10½
37	Clunch and bind	45	3	407	1½
38	*Coal*	1	5	408	6½
39	Black shale and bind	29	7	438	1½
40	*Soft Coal*	2	5	440	6½
41	Shale clunch, etc.	68	7	509	1½
42	*Coal*	3	9	512	10½

VERTICAL SECTION OF THE NOTTINGHAM AND DERBYSHIRE COAL-FIELD (*Continued*).

No.	Description of Strata.	Thickness.		Depth.	
		Ft.	In.	Ft.	In.
43	Shale and bind and a few small beds of iron-stone	82	3	595	1½
44	*Coal* (hard)	2	2	597	4
45	Clunch, bind, and shale	50	0½	647	4
46	*Main*, or *Top Hard Coal* (with clay partings)	8	2	655	6

The depths and thicknesses of the seams below the Top Hard coal in the same district as given by Mr. Aveline are as follows:—

———	Thickness.		Depth below Top, Hard.	
TOP HARD, OR RIFLER COAL.	Ft.	In.	Ft.	In.
Bind with ironstone	25	2	—	
Coal	0	10	424	5
Clunch and bind	11	0	—	
Coal	0	10	436	3
Bat, clunch, and bind	9	9	—	
Coal (probably the Ell coal)	1	0	447	0
Bind and rock	54	0	—	
Main or Deep Soft Coal	3	0	504	0
Bat	1	0	—	
Dark clunch and fire-clay	12	6	—	
Bind and rock	6	10	—	
The Deep Hard Coal	3	6	527	10

The following section gives the chief coals below the Deep Hard coal:—

	Thickness.		Depth below Deep Hard.	
	Ft.	In.	Ft.	In.
Clunch, bind, etc.	66	0	—	
Piper Coal	5	0	71	0
Bind, clunch, and other strata	138	0	—	
Furnace Coal	4	0	213	0
Clunch, bind, etc.	108	0	—	
Yard Coal	3	0	324	0
Clunch, bind, etc.	30	0	—	
Black Shale Coal	5	4	359	4
Clunch, bind, etc.	459	0	—	
Kilburn Coal	3	6	811	10
Depth of Kilburn coal below Top Hard coal	—		1,339	8

In Derbyshire the principal coals are the "Top hard" and "Lower hard" seams, producing the valuable splint-coal, the "Upper soft" and "Lower soft" coals; and in Yorkshire the most remarkable are the "Silkstone" and "Barnsley thick coals." The former is undoubtedly identical with the "Arley mine" of Lancashire; and thus this fine bed of coal, which seldom exceeds five feet in thickness, has originally spread over a tract embracing not less than 10,000 square miles!

Professor Green states that the Silkstone coal is perhaps the most highly prized of the Yorkshire seams. Where it occurs at its best it is bituminous, very pure, and has the highest reputation as a house coal. It occurs in two seams with a thin clay parting, and its thick-

ness varies from 3 to 6 feet. North of Cawthorne it deteriorates in quality.*

The Barnsley coal (known also as the Top Hard, Elsecar, and Gawthorpe coal) is the great seam of the Yorkshire coal-field. It derives its great value from the fact that a portion of the seam is semi-anthracitic, well adapted for use on locomotives, in steam-vessels, and for iron-smelting on account of its high heating power. The following is the analysis of the middle or hard portion of this seam at Lord Fitzwilliam's Elsecar Colliery † :—

Carbon 81·93, Hydrogen 4·85, Oxygen 8·58, Sulphur 0·91, Ash 2·46. The soft coal is sent to London, and only inferior portions are sold in the district.

The Upper and Lower Hard coals, and the Silkstone seam, produce that remarkably deep glossy coal with long fracture, known as "splint." Different seams have different qualities, and are suited for household, steam, or gas purposes.

In the Lower Coal-measures, or Gannister beds, described originally by Professor Phillips,‡ one or more of the coals, with their roofs of

* "Geol. Yorkshire Coal-field," p. 228-9.

† *Ibid.* 382.

‡ Article "Geology," in *Encyclopædia Metropolitana.*

black shale filled with *Aviculo-pecten papyraceus*, *Goniatites*, *Posidonomya*, etc., can be identified with those which range over North Lancashire: all of which facts go to prove the original continuity of these great coal-fields.*

The following section, including a portion of the Middle, and the whole of the Lower Coal-measures from the neighbourhood of Dewsbury and Halifax, will give a general view of the series as it occurs in the north-western portion of the coal-field: †—

Coal-series near Dewsbury and Halifax.

MIDDLE COAL-MEASURES.

	Ft.	In.		Ft.	In.
Haigh Moor Coal	2	11	to	4	0
Measures, with Thornhill and Dewsbury Rocks				340	0
Joan, or *Parson's Coal*	1	3	,,	2	3
Measures				58	0
Flockton Thick Coal, with partings (variable)				9	0
Measures				42	0
Flockton Thin Coal	1	5	,,	3	0
Measures, with *Old Hards*, or *Dawgreen Coal*				100	0

* See Mr. Binney, Trans. Geol. Soc. Manchester, vol. ii., part 7.

† Curtailed from "The Geology of Dewsbury," Expl. of Sheet 88, N.E. Mem. Geol. Survey, by Messrs. Green, Dakyns, Wood, and Russell.

	Ft.	In.		Ft.	In.
Coal			,,	1	1
Measures				68	0
Green Lane, or *Middleton Little Coal* .	0	6	,,	3	6
Measures				6	4
New Hards, or *Middleton Main Coal* .	2	0	,,	4	6
Measures				60	0
Wheatley Lime Coal	1	0	,,	3	0
Measures				94	0
Blocking, or *Toftshaw Coal* . . .	1	3	,,	2	4

LOWER COAL-MEASURES, OR GANNISTER BEDS.

	Ft.	In.		Ft.	In.
Measures				89	0
Lonsey Coal, of Whitley and Hopton .	0	5	to	2	8
Measures				78	0
Strata, with *Whinmoor Coal* . . .				38	0
Sandstone, with "Oakenshaw Quarry Stone"				170	0
Yards, or *Crow Coal*	0	2	,,	2	0
Measures, with *Ironstone* (worked at Low Moor)				36	0
Low Moor Black Bed Coal . . .	1	4	,,	3	0
Measures				119	0
Low Moor Better Bed Coal (very pure) .	1	0	,,	2	6
Fireclay	0	7	,,	4	0
Measures, with Elland Flagstone . .	270	0	,,	330	0
Measures, with 3 thin coals (Yards, Band)	176	0	,,	250	0
Halifax Hard Coal (*Gannister Coal*) .				2	8
Measures				30	0
Middle Band Coal				0	10
Measures				60	0
Halifax Soft Coal				1	6
Measures	80	0	,,	140	0
Thin Coal and Fireclay	1	0	,,	7	0

MILLSTONE GRIT in several beds, with intervening shales.

Over the northern portion of the Coal-field, between Bradford and the valley of the Calder from Dewsbury to Brighouse, the strata are much broken up by faults, which makes it impossible to represent this tract on the small index map.

Fossil Remains.—These have been summed up by Mr. Denny as consisting of 17 species of fish (placoid and ganoid). Of molluscs, 5 cephalopods, 17 conchifers and brachiopods. Crustacea, *Cythere* (Cypris). In the roofing shale of several of the coal-beds fish remains occur, and so plentifully in the case of one of these, at Middleton, that the miners call it the "fish-coal." In the roof of the "Halifax coal," of the Lower Coal-measures, *Goniatites Listeri* is found throughout its entire course, sometimes beautifully preserved in iron pyrites, and with this is associated *Avi-culo-pecten papyraceus.*

In the "Catherine Slack coal" near Halifax, *Nautilus Rawsoni* and *Orthoceras Steinhaueri* are frequent.

In the Middle Coal-measures there are bands of ironstone, filled, over a great extent of country, with *Anthracosia* (Unio) and *Cythere* (Cypris).

Extension of the Coal-field under the Permian and Triassic Formations.—Reserving to another chapter the full discussion of the question regard-

ing the extent and form of the coal-field under the newer formations, I may here state that I share the opinion of those who consider it most probable that this great coal-field is really a basin, partially exposed, partially concealed; and that east of a line which may be drawn through Wakefield and Worksop in a direction N.N.W. and S.S.E., the strata may be expected to rise towards the east, and ultimately to terminate somewhere beneath the Lias of Lincolnshire. This axis will probably be found to pass a little east of Shireoak Colliery, where the dip of the coals is slightly eastward, and which is consequently situated to the west of the axis. Under this view of the subject it will be observed, on referring to the General Map, that there is a larger extent of Coal-measures concealed than exposed at the surface.

The boring experiment in search of coal, which was carried out a few years ago at Scarle, near Lincoln, was calculated from its position to throw light upon the question of the extension of the Coal-measures under the newer formations,—and, if present, of their relations to the other rocks,—but unfortunately, although Carboniferous strata were undoubtedly reached, the cores brought up are of so peculiar

a character as to leave it uncertain to what portion of the Carboniferous formation they belong. They consist of beds of grey earthy limestone and shale, which might belong either to the Upper Coal-measures or to the Yoredale Beds lying at their base. The following is the section passed through :—

	Depths. Feet.	Thickness. Feet.
1. Alluvial Strata	1 to 10 ...	10
2. Lower Lias Clay and Limestone	10 ,, 75 ...	65
3. Rhœtic Beds	75 ,, 141 ...	66
4. New Red Marl and Sandstone .	141 ,, 1500 ...	1359
5. Permian Beds	1500 ,, 1900 ...	400
6. Carboniferous Strata . .	1900 ,, 2030 ...	130

The Carboniferous beds (6) appear to have been in a nearly horizontal position, and the following is a description of them :—

		Depths. Feet.	Thickness. Feet.
Carboniferous Beds.	Grey grits with plants . .		
	Shales with bivalves (Anthracosia)	1955 ...	55
	Bluish calcareous shales and earthy Limestone . .	2020 ...	65
	Fine breccia	2024 ...	4
	Chocolate-coloured hard clays .	2030 ...	6

The temperature at 2000 feet was 79° F., taken with one of Negretti's thermometers supplied by Professor Everett, of Belfast. At a depth of 917 feet, a strong feeder of water was

encountered in the Lower Keuper Sandstone, and a still stronger at 1250 in the Bunter Sandstone, when the water rose four feet above the ground. This water unquestionably percolates from a distance of ten or twelve miles underground.*

All along the edge of the escarpment of the Magnesian Limestone, and for a short distance beyond, in Notts and Derbyshire, as far north as Rotherham, the coal-seams are found to dip eastward, at a greater angle than the Limestone itself, which, with the Lower Red Sandstone, rests unconformably on the Coal-measures. At Shireoak Colliery, the full thickness of 327 feet of the Permian beds was passed through in the shafts, which commence at the base of the New Red Sandstone. North of Wakefield, the beds generally tend to rise towards the north-east, near to, and under, the Magnesian Limestone; and in the centre of the coal-field, the Ackworth Rock (a red sandstone), which is an outlier, and is amongst the highest of the Carboniferous beds,

* This boring was commenced in 1873 by a local company, for the purpose of testing the presence of coal in the neighbourhood of Lincoln,—Mr. J. T. Boot, of Mansfield, being the engineer,—and was carried out by the Diamond Rock Boring Company.—Minutes of Proc. Inst. C. E., vol. xlix., Part 3 (1877).

represents the central position of the whole basin.* The views of Professor Ramsay, the Commissioner who has reported on this subject, are so important that I take the liberty of quoting the general summary of them in his own words:—

"It has been shown in the evidence that the Yorkshire, Derbyshire, and Nottinghamshire coal-fields probably lie in the form of a basin, the northern, southern, and eastern edges of which lie underneath the New Red, Permian, and other overlying Secondary strata. The centre of this basin are the Ackworth and Rotherham rocks, forming the topmost beds of the Coal-measures, about three miles west of the edge of the Magnesian Limestone. When the different subdivisions of the Coal-measure strata are extended underneath the Permian and New Red beds, and carried round concentrically from south to north, the area of available Coal-measures beneath the Permian and other overlying beds may be roughly estimated at about 900 square miles; this con-

* See Professor Ramsay's views on this subject in the Report of the Coal-Commission, vol. i., pp. 136-8, in which the whole evidence is handled with great ability, and leads the Commissioner to adopt the view of the basin-like form of the coal-field. This view is also supported by Professor A. H. Green, of the Yorkshire College of Science, Leeds (*ibid.*, vol. ii., p. 504), whose evidence is illustrated by a sketch-map.

cealed portion of the coal-basin being approximately equal to the coal-field exposed at the surface. It is estimated that, exclusive of part of the Gannister beds, the whole of the important coals of the coal-field lie underneath the New Red Marl, etc., and even a small part of the lower Lias, at depths of 4,000 feet and under; for the gradual increase of thickness due to the coming on of successive formations of Magnesian Limestone, New Red Sandstone, Red Marl, and Lias, is probably compensated for by the gradual rise of the eastern edge of the basin towards the base of the lowest formation overlying the Coal-measures. If this assumption be correct, then deducting the amount given by the late Mr. Woodhouse as proved under the Permian formation, namely, 8,306,140,050 tons, there remain about 23,083,000,000 tons still further available, a great part of which will lie at depths under 3,000 feet. The following are the proportions :—

"Area east of the Permian escarpment :—

	Tons.
672 square miles, 40 feet coal .	26,768,179,200
132 ,, 20 ,, . .	4,620,697,600
	31,388,876,800
Deduct proved under Permian beds	8,306,140,050
	23,082,736,750 "*

* This is the gross estimate, not the "available" net quantity after deductions.—See Report, p. 31.

Depth of the Top Hard Coal along eastern border.—As the Magnesian Limestone is everywhere unconformable to the underlying Coal-measures, we find it resting indifferently on all the beds from the Millstone Grit, N.E. of Leeds, to the highest beds of the Coal-measures opposite Barnsley. The depth of the Top Hard Coal will, therefore, everywhere vary, and the following are its proved or estimated depths at various points from north to south,* along the margin of the Limestone :—

1. East of Barnsley and the Ackworth Rock, to Top Hard Coal, 1,850 to 1,900 feet; and to Silkstone Coal, 2,850 to 2,900 feet.
2. Under Bolsover, to Top Hard Coal, 900 to 950 feet; to Lower Hard Coal, 1,500 to 1,550 feet.
3. Opposite Torkard, to Top Hard Coal, 1,236 feet.
4. Opposite Kirkby Woodhouse, to Top Hard Coal, 700 to 750 feet.
5. Langwith Colliery, 5 miles N. of Mansfield, to Top Hard Coal, 1,620 feet.†
6. At Peasley Colliery, near Mansfield, the Top Hard Coal has been reached at 1,545 feet.
7. Under Newstead Abbey, to Top Hard Coal, from 1,500 to 1,600 feet.
8. Under Felley Abbey, to Top Hard Coal, 800 feet.

Thickness of the Magnesian Limestone.—This formation increases in thickness northward,

* Coal-Commission Report, vol. i., p. 137.

† Communicated by Mr. J. T. Boot, Mining Engineer of Mansfield.

partly by the swelling out of the strata, and partly by the appearance of new beds. The following estimates of thickness at several points have been prepared by Mr. Russell, of the Geological Survey :—

In the neighbourhood of Longhills, near Hucknall Torkard . . .	about	100 feet.
Near Annesley	,,	120 ,,
Near Kirby Forest	,,	100 ,,
Near Warsop	,,	140 ,,
Near Shireoaks	,,	318 ,,
Near Doncaster	,,	360 ,,
At Custon Park	,,	262 ,,
At Byram Hall (4 miles N.E. of Pontefract)		312 ,,

Resources.—The estimates of the resources of this coal-field, as far as it extends westward of the Magnesian Limestone, and a certain tract under this formation, where the coal has been proved by actual mining, were entrusted to the late Mr. J. T. Woodhouse, one of the members of the Coal-Commission. These estimates considerably exceed those made by myself, partly from including seams under two feet in thickness, and, partly, because Mr. Woodhouse from the gross sum has made a smaller proportionate deduction for waste, and the quantity extracted, than that by myself. In this latter point I now feel satisfied he has formed a truer estimate, and

I, therefore, willingly substitute his figures for my own; but if I also adopt the larger figure he gives for the amount available it is under protest against including very thin seams for great depths. In adopting this course, however, Mr. Woodhouse was only following the rule laid down by the whole of the Commissioners for their own guidance.

Visible Coal-field.

1. Area of Coal-field, beyond the margin of the Magnesian Limestone and Permian	760 square miles.
2. Greatest thickness of productive Coal-measures, including the Lower series	4,500 feet.
3. Average number of workable coal-seams above 2 feet, 15; giving a vertical thickness of coal . .	46 feet of coal.
4. Average number from 1 foot upwards, 20, with	53 ,, ,,
5. Quantity of coal remaining unworked (4,500 feet) . . .	24,441 millions of tons.
6. Quantity available for consumption down to a depth of 4,500, 13,747,000,000; deduct for quantity beyond limit of 4,000 feet, 1-9th,* leaving net available quantity down to 4,000 feet (1870)	12,220 ,,
7. Net available quantity in 1880 .	12,000 ,,

* I have been obliged to make the reduction from Mr. Woodhouse's estimate, in order to keep within the limit of 4,000 feet.

Concealed Coal-field.

8. Area overspread by Permian, Trias, and Lias, as estimated by Professor Ramsay *	900 square miles.
9. Total quantity of coal under this area, at a depth not exceeding 4,000 feet	23,082 millions of tons.
10. Deduct for quantity not available from various causes, 1-3rd (7,694 mil. tons), leaving for future use	15,388 millions of tons.

Summary.

1. Net available quantity of coal of exposed coal-field	12,000,000,000
2. Net available quantity of concealed coal-field	15,388,000,000
Total available supply .	27,388,000,000

The produce of this coal field has taken a great bound forward during the last twenty years, having increased from 12,497,100 tons in 1859, to 17,865,367 tons in 1869, and to 26,886,160 in 1878;† the number of collieries has also increased from 559 to 808 in the same period, and of these several are situated on the Magnesian Limestone.

* See *ante*, p. 263.

† "Mineral Statistics," 1878.

CHAPTER XXI.

GREAT NORTHERN COAL-FIELD OF DURHAM AND NORTHUMBERLAND.

The general succession of the strata and their relative position over the area of this coal-field is similar to that of Yorkshire, so that one section will serve to illustrate the structure of both. I must therefore beg the reader to refer to the transverse section at the commencement of the last chapter (Fig. 16, p. 246).

The Great Northern coal-field extends from Staindrop near the north bank of the Tees, on the south, to the mouth of the Coquet, where it enters Alnmouth Bay, on the north, the distance being nearly 50 miles. Its greatest diameter is near the centre, along the course of the Tyne, which forms the great highway for the export of coal to the London market.*

* I have calculated the area of this coal-field from Mr. W. Oliver's map in the *Mining Record* office. There are some interesting details in "Our Coal and our Coal-pits," published by Messrs. Longman.

From the Coquet to the Tyne the North Sea forms the limits of the coal-field. South of this the escarpment of the Lower Permian Sandstone and Magnesian Limestone forms the boundary at the surface; but the Coal-measures underlie these newer rocks; and since Dr. William Smith,* first on theoretical grounds, and afterwards by actual experiment, demonstrated the existence of the coal-field at Haswell near Durham, both the Triassic and Permian formations have been perforated over a large area, especially at Seaham and Ryhope in Durham.

Form and structure of the Coal-field.—Recent observations have tended to confirm the opinion, that the structure of this coal-field is that of a trough, or irregular basin, of which the longer axis lies in a north and south direction, stretching from the apex near the mouth of the Coquet, through North Seaton and Jarrow Collieries on the north of the Tyne, and through Monkwearmouth Colliery,† below the Magnesian Limestone to the south of that river.‡ The examination

* About half a century ago.

† At this colliery the coal-seams descend to a depth of 2,268 feet below the surface.

‡ This view is supported by Professor Ramsay, and by Mr. H. H. Howell, of the Geological Survey, in his evidence before the Coal-Commission.—See Report, vol. i., p. 138.

of the coast-sections north of the Tyne, the results of which are laid down on the Geological Survey maps by Mr. Howell, places it beyond question that the beds rise towards the north-east, or in the seaward direction. Nor is there any reason to suppose this to be a mere local uprising of the strata ; on the contrary, it may be considered as the commencement of a normal arrangement ultimately resulting in an easterly outcrop under the sea-bed itself.

The southern limits of the basin are also capable of being defined with tolerable accuracy. The Magnesian Limestone (which with the Lower Permian Sandstone has been pierced by several coal-shafts), rests unconformably on the coal-formation, and near Hartlepool some of the seams have been proved to rise towards the south, and terminate against the bottom of these newer rocks. The lowest workable coal-seam, called the "Brockwell" coal, passes at its outcrop under the Magnesian Limestone immediately east of Shildon, dipping to the north-west at an angle of 15° to 18°.* This then gives us the line of the southern margin, which Professor Ramsay considers may be drawn from Seaton Carew, north of the entrance to the Tees, west-

* Mr. Howell, Evidence, *supra cit.*

ward to Middridge Grange, four miles south-east of Bishop Auckland. To the south of this line, the Permian and Triassic strata would be found to overlie only Millstone Grit and Yoredale rocks.*

The regularity of the basin-like form towards its southern margin is somewhat interrupted by the presence of a fault, known as the "Butterknowle Dyke," which ranges in a W.S.W. and E.N.E. direction, depressing the strata on the south to the extent of 700 feet, and bringing in the upper measures with all the coal-seams from the "Five-quarter" downward under the Permian rocks at Leasingthorne, Black Boy, and Eldon Collieries.† To the south of this fault the strata dip rapidly toward the N.N.W., thereby bringing the lowest seams in contact with the overlying Permian formation, and ultimately the Millstone

* Professor Ramsay, *ibid.* Sir R. Murchison, in his address, delivered at Nottingham, has expressed a doubt of the extension of the coal-measures south of the Tees, where they were bored for at Middlesborough by Mr. Vaughan, to a depth of 1,313 feet. At the bottom of the bore-hole, rock-salt was encountered, but even the Permian Magnesian Limestone had never been reached. See Sir R. Murchison "On parts of England where Coal may or may not be looked for" (Trans. Brit. Assoc. Nottingham, 1866).

† Mr. H. H. Howell, quoted by Prof. Ramsay, Rep. Coal-Com., vol. i., p. 139. See map, section, and description of the Northern Coal-field, by Mr. Dunn, Trans. North of England Institute of Mining Engineers, vol. xii.

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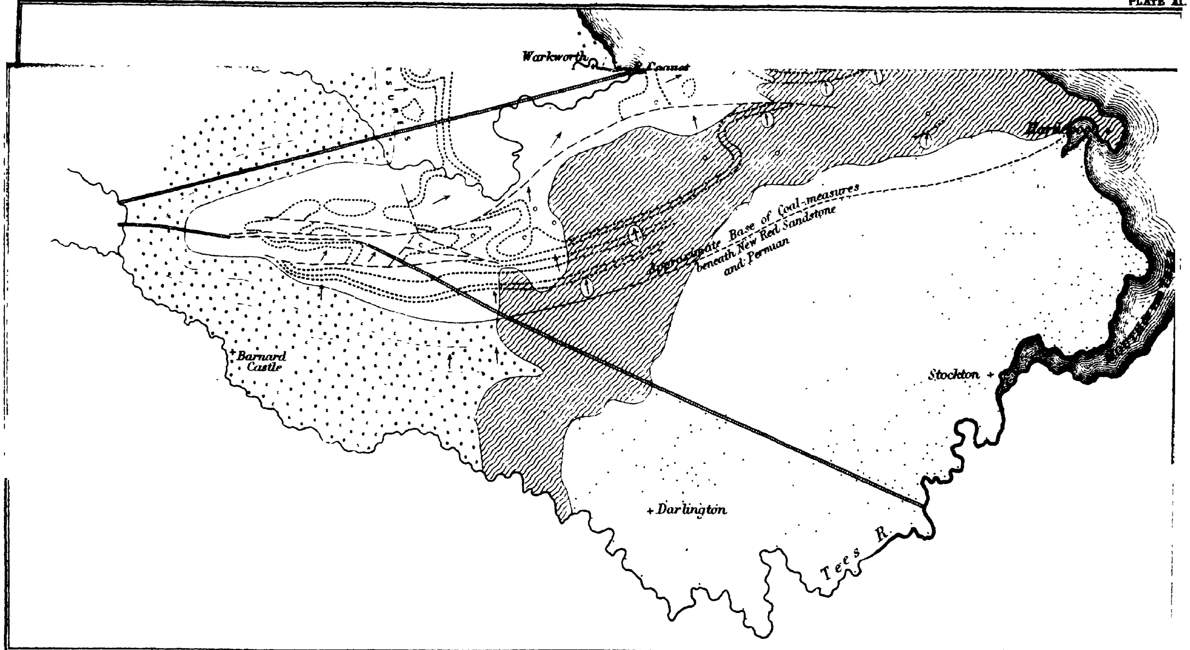
PLATE XI.



Stanford's Geog.l Estab.t London.

London: Edward Stanford, 55, Charing Cross.

Grit itself, from its visible outcrop near Heighington, eight miles north-west of Darlington.*

From below the coal-field of Durham and Northumberland the Lower Carboniferous Rocks rise towards the west and north into swelling moorlands, and ultimately into the mountainous tracts of the Pennine chain, attaining at Cross Fell a height of 2,930 feet.

General Series of Formations.†

New Red Sandstone.—Red sandstone and conglomerate.

Permian Rocks. Magnesian Limestone. 600 to 700 feet.	1. Upper Permian marls, with gypsum	100 ft.
	2. Crystalline limestone, with *Schizodus Schlotheimi*, and *Mytilus septifer.*	
	3. Brecciated limestone (Tynemouth Cliff), lying on—	
	4. Fossiliferous limestone, with *Productus*, *Strophalosia*, *Athyris*, *Avicula*, etc., and numerous Polyzoa.	
	5. Compact limestone, with similar fossils.	
	6. Marl slate, calcareous shales, and thin-bedded limestone, with fishes of the genera *Palæoniscus*, *Acrolepis.*	
Upper Carboniferous.	7. Yellow sandstone, upper red sandstone, with gypseous marl, *Pinites*, *Brandlingi.* *Trigonocarpum*, *Sigillaria reniformis*, *Calamites approximatus*	200 ,,

* Mr. George Elliot, Rep. Coal-Commission, vol. i., p. 26.

† From the works of Professors Sedgwick and King.

Coal-measures, 2,030 feet.	1. Upper series, with thin coals, and a band of ironstone, with *Anthracosia*, *Lingula Credneri*, *Leperditia inflata*, *Holoptychius Hibberti* . .	900 ft.
	2. Middle series. From the "High Main Coal" to the "Brockwell Coal" . .	2,000 ,,
	3. Lower Coal-measures, with 2 beds of coal, between 2 and 3 feet thick with marine shells.*	150 ,,
Millstone Grit	— Coarse grits and shales . .	414 ,,
Yoredale Rocks or	— Shale, with bands of limestone and thin coals . . .	540 ,,
Bernician Series†	— Ten beds of limestone, parted by as many beds of shale, containing coal-seams in Northumberland, upwards of	1,120 ,,‡
Tuedian Series	— Grits, conglomerates, shales, and limestones, etc., with plants and *Anodonta Jukesii* . .	

Coal-seams.§—The most important coal in the Newcastle district is the "High main" or

* Discovered by Mr. G. A. Lebour, F.G.S. See *Nature*, 23rd Feb., 1878.

† Professor Phillips' "Manual of Geology," p. 163.

‡ For a list of the fossils of the Permian and Upper Coal-measures, see Mr. J. W. Kirkby, Journ. Geol. Soc., vol. xvi., p. 412.

§ For the details of the coal-seams, I am indebted to Mr. Dunn, late Inspector of Collieries.

"Wallsend" seam. It is the highest workable coal, and varies from 5 to 6 feet in thickness. It is traversed by the "90-fathom" dyke, and is persistent in its general character to its northern and western outcrop, but southward towards the valley of the Wear is split up into two seams by the intercalation of sandstone and shale.

The "Bensham" seam, 20 fathoms below the "High Main," is very variable in its qualities, and is often unworkable. It acquires its chief value towards the east, and is worked extensively under the Magnesian Limestone at Sunderland. Its general thickness is 6 feet.

The "Low Main" seam is known to range from Widdington on the north to Ferry Hill on the south, a distance of about 40 miles. This coal, south and west of Newcastle, is moderately soft, and excellent for household use and coking. But passing northwards its character changes; it becomes very hard and less gaseous, and constitutes the most important bed of steam-coal. Below these lie several other seams, which will become more extensively worked as the supply from the valuable beds above described becomes curtailed.

The following is a list of the general series

of coal-seams, for which I am mainly indebted to Mr. Dunn:*—

Coal-series of Northumberland and Durham.

(NEWCASTLE DISTRICT.)

			Ft.	In.
Upper Series.	*Closing Hill Seam*		1	8
	Strata		450	0
	Hebburn Fell Seam		2	8
	Strata		250	0
	Five-quarter Seam		4	0
	Strata		260	0
	Three-quarter (Black close) *Seam*		2	0
	Strata	50 to	180	0
1.	*High Main Coal*		6	0
	Strata	From 33 to	150	0
2.	*Metal Coal*		1	6
	Strata		33	0
3.	*Stone Coal*		1	6
	Strata	60 to	100	0
4.	*Yard Coal*	(variable)	2	10
	Strata	60 to	100	0
5.	*Bensham Coal*	2 ft. 5 in. to	5	0
	Strata		78	0
6.	*Five-quarter Coal*		3	0
	Strata		48	0
7.	*Low Main*, or *Hutton Coal*		6	0
	Strata	30 to	100	0
8.	*Crow Coal*	(inconstant)	2	10
	Strata		24	0
9.	*Five-quarter Coal*		3	8
	Strata		30	0

* I have also availed myself here and elsewhere of the information contained in Mr. G. A. Lebour's "Outlines of the Geology of Northumberland" (1878).

		Ft.	In.
10.	*Ruler Coal*	1	10
	Strata	96	0
11.	*Townley*, or *Harvey Coal*	3	1
	Strata	42	0
12.	*Jetty Coal*	2	2
	Strata	42	0
13.	*Stone Coal*	2	5
	Strata	18	0
14.	*Five-quarter Coal*	3	4
	Strata	30	0
15.	*Three-quarter Coal*	2	6
	Strata	54	0
16.	*Brockwell Coal*	2	11

The series below the Low Main Coal is taken at Blaydon and Wylam, as the coals have never yet been worked at Newcastle.

The Brockwell coal has been taken by the Geological Survey as the boundary, between the Middle and the Lower Coal-measures or Gannister Beds, which form a band underneath, with some thin coals and marine fossils, including *Aviculo-pecten papyraceus*, discovered recently by Mr. Lebour near Whittonstall.* The Millstone Grit follows, also containing some thin seams, but decreased in thickness and deficient in character; underneath which comes the great "Bernician Series," consisting of numerous beds of limestone, of grits, sandstones, shales,

* Geol. Magazine, March 1878.

and beds of coal, in all about 2,500 feet in thickness, representing the Yoredale Beds of the North of England, and the Lower Coal-measures of Scotland. Some of the lowest beds of Limestone probably represent the Carboniferous Limestone formation of Derbyshire.*

The following is the series of coals in descending order, as given by Mr. Lebour,† belonging to the "Bernician Series," and underlying those in the above list:—

Middle and Lower Carboniferous Coals.

(BERNICIAN SERIES.)

1. *Little Limestone Coal*—in 3 seams, of which the "Rough" and "Licker" are the chief.
2. *Great Limestone Coal*—or Dryburn Coal, worked at Lowick.
3. *Shilbottle Coal*—below the "Six-yard Limestone."
4. *Beadnell Coals*—below the Beadnell Limestone; in 2 seams, of which the lower reaches 6 feet.
5. *Oxford Limestone Coals*—below the Oxford Limestone, in four principal seams.
6. *Dunstone Coals*—below the Dun limestone; in 3 seams.
7. *Blackhill Coal*—also called the "Little Howgate Coal."
8. *Hardy Coal*—sometimes in 2 seams.
9. *Bulman Coal*—five fathoms below the last.
10. *Three-quarter Coal*—about 18 fathoms below the last.

* This point is more fully explained in my paper on the Classification of the Carboniferous Series. Quart. Journ. Geol. Soc., Nov. 1877, p. 635.

† *Supra cit.*, p. 39.

11. *Cooper Eye Coal*—also known as the Stony Coal; 3 or 4 fathoms below the last.
12. *Wester Coal*—about 10 fathoms below the last.

Basaltic Dykes.—The coal-field is traversed by several narrow basaltic dykes, generally ranging a little south of east, and running for several miles in nearly straight lines. The beds of coal on approaching these dykes become anthracitic, and ultimately worthless. Mr. Lebour separates them into two sets, the first ranging nearly east and west, and the second north-east and south-west. To the former are referable those of Hebburn, Cramlington, Bedlington, Lower Wansbeck, Acklington, Trobe's Dene, Beadnell, and Holy Island, or Lindisfarne, one of the largest in the country. Those of the second set are the Brunton, Bavington, Lewis Burn, Blackburn, Plashetts, Boulmer, Hampeth, Howick, and Cornhill. The Cock-field Fell dyke in South Durham ranges from W.N.W. to E.S.E. These dykes are newer than any of the strata with which they come in contact; they also cut across the Faults; and from their resemblance both in composition and mode of behaviour to those which traverse the Carboniferous beds of Scotland, Profesor Geikie has arrived at the conclusion that they are of the same Miocene age as those

of the latter country.* Many of the above dykes have altered and baked the strata which they traverse, the coal being sometimes completely coked, or converted into cinder; at other times, however, their effects are less obvious. Besides the dykes which reach the surface, there are others which only burrow below, and in rare cases, some have been found to overflow, as in the case of the Acklington dyke, where it approaches the Cheviot Hills. Other cases are known, which have been described by Mr. J. Lothian Bell.† On the other hand, the upper limit of one of these dykes, where it bifurcates and terminates below a bed of Sandstone, is exposed to view on the coast a little south of Seaton Sluice.‡

Faults.—One of the largest of these is the "Ninety-fathom Dyke" of Denton Colliery. Along its course the strata are depressed on the north side to the extent of 200 fathoms between Gosforth and Killingworth. Most of the east and west faults do not traverse the Magnesian Limestone, being of anterior age to its formation.

Coal under the Sea.—To what distance from the shore coal will be available, is a question

* Trans. Brit. Assoc. 1867, p. 51.

† Proc. Roy. Soc., vol. xxiii., p. 543.

‡ Lebour, *supra cit.*, p. 48.

which cannot be directly answered, as every seam presents the problem under a different aspect. Questions regarding depth, thickness, regularity, and absence of faults, as well as the nature of associated strata, are here presented in relation to the coal-seams themselves; and depth of sea-bottom in relation to the sea. In every case a considerable breadth of coal where it approaches the outcrop must necessarily be left as a barrier; and it is unquestionable, that faults traversing the strata under the sea, at a considerable depth and pressure of water, and especially if there are beds of porous sandstone overlying the coal-seams, would give facilities for the influx of sea-water into the mines so as to prevent, or impede, the working of the coal.

With reference to this special coal-field, Mr. Elliot considers that, in that portion of the district south of the Tyne, a minimum distance of 3½ miles may be included as available; and that it is possible that a much wider extent will ultimately be worked by means of shafts sunk below the sea itself at a distance from the shore;* on the other hand, Mr. Forster assumes a distance of only two miles in breadth along the coast for that part of the coal-field north of the

* Report, Coal-Commission, vol. i., p. 26.

Tyne. This difference of opinion, on the part of gentlemen of such experience in mining undertakings, is a sufficient proof that the question is at present involved in much uncertainty.

In the following estimates of resources, I have adopted those of the Commissioners, after rejecting all seams from 18 inches in thickness downwards, amounting to about 176 millions of tons; at the same time that I adopt their estimates of the quantity available below the sea to a distance of 2 and 3½ miles from the shore respectively.

Resources.

In estimating the extent of this coal-field, we must include not only the area of the visible tract of Coal-measures beyond the limits of the Permian formation, but that also which is concealed beneath this formation, though now very nearly proved over its whole area. Along with this is included, by Mr. Forster, 40 square miles of sea-covered coal, of an aggregate thickness of 14 feet, distributed into four seams; and by Mr. Elliot 71 square miles, with an aggregate thickness of 30 feet distributed in six seams.*

* If I understand Mr. Elliot rightly, he takes a breadth of 7 miles out to sea, giving 1,500 millions of tons for the area

1. Area of visible coal-field, beyond the limits of the Permian and New Red Sandstone . . .	460 square miles.
2. Area of concealed coal-field . .	225 ,,
3. Area under the sea supposed to be available	111 ,,
4. Number of workable seams from 18 inches upwards, 16; giving a thickness of available coal .	46 feet.
5. Net available quantity of coal on land, after necessary deductions for loss, etc. (Northumberland) .	2,576,000,000 tons.
6. Net available quantity under the sea	403,000,000 ,,
7. Net available quantity on land (Durham), including seams down to 12 inches in thickness, 3,988,000,000 tons; deduct 1-16th for seams from 18 inches downwards, as determined in Mr. Forster's district; leaving .	3,738,750,000 ,,
8. Quantity under the sea (Durham Coast), including a breadth of $3\frac{1}{2}$ miles, with an area of 71 square miles	734,500,000 ,,
Total (in round numbers)	7,452,250,000 ,,
Deduct quantity worked out since 1870, being about 300,000,000 tons, and there remain for future use (1880)	7,152,000,000 ,,

Lower Carboniferous Coals.—These have already been described under the head of the

beyond the minimum limit of $3\frac{1}{2}$ miles. How does he intend to guard against storms in the cases of his submarine shafts? Unless situated on an island, a N.E. gale would sweep away any colliery that could be planted.

"Bernician Series," and Mr. Nicholas Wood,* in giving a full account of the coals of Northumberland, states that they are worked at Talkin, Tindal Fell, Fourstones, Acomb, and Fallowfield. A very interesting section of the series is tabulated by Mr. Hutton, from the Millstone Grit down to the "4-feet seam" of Tindal Fell, for which I must refer the reader to the memoir itself.†

The available quantity of coal in this district was estimated by Mr. Forster (in 1870) at 665,180,000 tons, or, rejecting all seams under 18 inches, at 580 millions of tons, which, added to the former, gives a total available quantity from the Carboniferous rocks of this part of England,—

1. Upper Carboniferous coal . .	7,152,000,000
2. Lower Carboniferous coal . .	580,000,000
Total	7,732,000,000 tons.

Notwithstanding that the Great Northern coal-field has been drawn upon more heavily than any other of the British coal-fields, and for a larger period, the produce has rapidly increased during the last quarter of a century. This is partly due to the creation, and prodigious expansion, of

* Trans. Nat. Hist. Soc. Northumberland, vol. i.
† *Ibid*, vol. ii., p. 24.

iron-manufacture along the estuary of the Tees, which has its centre in Middlesborough; and partly to the enormous demands from the metropolis of England.

In 1859, the produce of this coal-field was 16,001,125 tons from 183 collieries; in 1869, or ten years later, the produce reached 25,765,430 tons from 297 collieries; and of this 4,959,647 tons were converted into coke, chiefly for iron-smelting. In 1878, the produce was 30,133,884 tons.*

Plainmeller Coal-fields.—High amongst the moors of Northumberland, about four miles south-east of Haltwistle, we find three little coal-fields lying along the side of a large east and west down-threw fault. They are formed of true Coal-measures with Gannister Beds of slight thickness below, and these reposing on Millstone Grit. There are in all five coal seams, the lowest of which, "the Cannel seam," is included in the Gannister Beds. The general dip of the beds is south, at a moderate angle, and on the south of the great fault the Yoredale Beds reach the surface.†

* "Mineral Statistics," for 1859, 1869, and 1878.

† See 6-inch Geol. Survey Map of Northumberland, No. 92, by Mr. D. Burns.

CHAPTER XXII.

COAL-FIELDS OF SCOTLAND.

IT will be observed, on looking at a geological map of Scotland, that the series of formations of which that country is composed, are arranged in bands crossing the island from south-west to north-east; and, on the whole, parallel to the central range of the Grampian mountains.

The Carboniferous series of Scotland forms one of these bands, stretching from sea to sea, and occupying a trough between the southern slopes of the Grampians on the one side, and the indented flanks of the "Southern Uplands" on the other. These are composed of Old Red Sandstone and Silurian rocks, stretching from Kirkcudbrightshire to Berwick, of which the Lammermuir, Moorfoot, and Lead Hills form a part. The height of many of these hills is considerable. Merrick Hill reaches an elevation of 2,751 feet, Cairns-Muir-of-Deugh 2,597, Black Larg 2,890, and Black Hope Scar 2,136 feet.

The western margin of the Carboniferous area is washed by the Firth of Clyde, and the river itself drains a large tract of the great central coal-basin. The eastern limit is the North Sea on both shores of the Firth of Forth. The northern boundary line leaves the river Clyde east of Dumbarton, passing along the southern slopes of the Kilpatrick, Campsie, and Stirling Hills, and continuing by Kinross and Cupar, enters the sea at St. Andrew's Bay.

The southern boundary is much indented in some places, but ranges in a north-easterly direction from Girvan, on the Ayrshire coast, to Dunbar. Throughout the greater part of its course the line of junction between the Carboniferous and Older Palæozoic formations is a fault, with a downthrow to the north, which has been traced on the maps of the Geological Survey. The extreme length from the coast of Ayr to Fifeness is 94 miles, the average breadth 25 miles.

This great range of Carboniferous rocks is not all productive of coal; hence the coal-bearing series forms several distinct fields or "basins," separated either by physical barriers, as firths and rivers; or by the uprising of the Lower unproductive Carboniferous, or Old Red Sand

stone rocks, where the coal-series has been swept away. These separate fields may be thus denominated:—1. The coal-field of the Clyde Basin. 2. Mid-Lothian and Haddington coal-field. 3. The Fifeshire coal-field. 4. The Clackmannan coal-field. 5. The Ayrshire coal-field. 6. The Lesmahago coal-field.

Geological Age of the Scottish Coal-fields.—While England and Wales have only one series of beds producing coal-seams of much value, Scotland, on the other hand, is blessed with two series. The Upper of these is on the same geological horizon as the true Coal-measures of England lying above the Millstone Grit, while the Lower underlies this formation, and occupies the position of the Bernician series of Northumberland, and of the Yoredale Beds of the north and central portions of the country. These two coal-bearing formations are known as "the Upper Coal-measures," or "Flat Coal Series," and the "Lower Coal and Ironstone Series" of Scotland respectively; the reason being, that as the former generally occupy the central portions of the basins, they are but slightly inclined, while the latter being more marginal, are generally highly inclined along their outcrop.

The appearance of coal-seams and beds of

limestone in Durham and Northumberland lying between the Millstone Grit on the one hand, and the Derbyshire Limestone on the other, will have prepared the reader for the condition of things as he finds them in Scotland. The change may be briefly stated as consisting of the introduction towards the north of beds of limestone and coal in the "Yoredale series," and the concurrent splitting up and thinning out of the solid mass of the Carboniferous Limestone in the same direction. The Millstone Grit is also greatly reduced in thickness as compared with its development in Lancashire and Derbyshire; and the "Gannister Beds" are represented only by a few feet of strata. On the other hand, the Lower Coal and Ironstone series of Scotland are characterized by minerals of great value, consisting of ordinary coal, cannel, oil shale, black-band and clay-band ironstone, and limestone, all of which have largely contributed to the rise and progress of trade and manufactures in the central districts of that country.*

* The general opinion is, that the Lower Coal-series of Scotland is in the position of the Carboniferous Limestone. From the above statement it will be seen that I do not concur in this view for reasons stated in my paper on "the Carboniferous Series"—Quart. Journ. Geol. Soc., No. 132, p. 633.

General Succession of the Carboniferous series of the Centre of Scotland.

The whole of the Carboniferous rocks are divisible into four groups, which in Fifeshire, Haddingtonshire, and Berwickshire, repose conformably upon the Old Red Sandstone, which seems to graduate into the Lowest Carboniferous strata.

	Divisions.	English equivalents.
Upper Coal-measures. 200 feet.	Red sandstones of Bothwell, Hamilton, etc., without coal-seams. This series in Ayrshire contains a seam of limestone with *Spirorbis*, and rests unconformably on the beds underneath.	Upper Coal-measures of Manchester, etc.
Flat Coal-measures.	Sandstones, shales, fire-clays, and coal-beds, with fish-remains, *Anthracosia*, *Anthracomya*, etc.	Middle Coal-measures.
Lower Coal-measures.	Shales, etc., with the "slaty-band," ironstone, and marine shells, *Discina nitida*, *Axinus*, *Conularia*, etc.	Gannister Beds, etc.
Moorstone Rock, or *Roslin Sandstone.* 400 feet.	Thick-bedded reddish and yellowish sandstones, shales, etc., down to the Garnkirk limestone.	Millstone Grit.
Lower Coal and Ironstone series.	Bands of limestone, shales, sandstones, coals, black-band ironstone, oil-shale, etc., fish and entomostraca.	Yoredale Beds; (Bernician series).

	Divisions.	English equivalents
Carboniferous Limestone series.	Beds of limestone and shale, including the Roman Camp, and Gilmerton limestone.	Carboniferous Limestone.
*Calciferous Sandstone series.**	(*a*) The upper, yellow, and white freestones, shales and freshwater limestones of Burdie-house, etc. (*b*) Dull reddish sandstones, shales, and conglomerates.	Lower Limestone shale; (Tuedian series.)

With the exception of the two uppermost divisions, and occasional beds of estuarine strata, the whole of the above series may be regarded as of marine origin, attaining a combined thickness of 8,000 or 9,000 feet. The beds are largely intermixed with rocks of plutonic and volcanic origin, and in Ayrshire are overlaid unconformably by representatives of the Permian system, which occupy a small tract near the centre of the coal-field.† With this general introduction, I now proceed to give some details regarding the individual coal-fields.

* Mr. R. Etheridge, jun., has shown that notwithstanding the occasional occurrence of lacustrine beds (such as the "Burdie House Limestone"), several beds with marine invertebrata occur throughout the series *b*, which may therefore be regarded as to a large extent of marine origin. See Quart. Journ. Geol. Soc., vol. xxxiv., p. 1.

† Messrs. A. and J. Geikie—"Explanation of Sheet 14" (Ayrshire), Mem. Geol. Survey, p. 22.

CHAPTER XXIII.

COAL-FIELD OF THE CLYDE-BASIN.

THIS Basin includes portions of Renfrewshire, Dumbartonshire, Stirlingshire, and nearly the whole of Lanarkshire; and is traversed throughout its whole length by the River Clyde, along whose banks, above Glasgow, fine sections of the strata are laid open. At the base of the whole series are the Lower Calciferous Sandstones, which are overlaid by the higher beds of this division, and with which are associated great sheets of contemporaneous traps, ashes, and agglomerates, which form the general base of the coal-bearing strata of the district.

These volcanic rocks of the Lower Carboniferous period rise into terraced hills, both to the north and south of the Clyde Valley, stretching from Dumbarton to Stirling, by Kilpatrick and Campsie, and from Greenock, by Neilston, to the neighbourhood of Stonehouse, where, however, along the valley of the Avon, they are unconformably overlapped by the Carboniferous Limestone-

series, which rests directly on the Old Red Sandstone.* Towards the east, the Lanarkshire coal-field is separated from those of the Lothians by the uprising of the Calciferous Sandstone-series, which in the district of Linlithgow attains a thickness of nearly 4,000 feet.

Trap Rocks.—Besides the great sheets of fel stone, porphyrite, and melaphyre, which were poured out at the earlier stage of the Carboniferous period, the strata are invaded by other igneous rocks, referable to (at least) two periods. These occur as sheets of melaphyre and dolerite, which have been intruded amongst the coal-strata in a fluid or viscous state, and are frequently the cause of much loss or difficulty in mining operations.† These rocks are probably referable to the age of the Upper Carboniferous series themselves, or possibly of the Permian. In addition to these intrusive sheets, there are also vertical dykes of basalt and dolerite, which range in nearly east and west lines for miles through the strata, and have been referred, with much probability, by Professor Geikie, to the Miocene Ter-

* Dr. James Geikie, *supra cit.*, p. 5.

† One of these sheets forms the prominent ridge on which the Glasgow Necropolis is situated, from which a noble view of the Clyde Valley and of the city of Glasgow, with its venerable Cathedral, is to be obtained.

tiary period.* There are thus to be found amongst the Carboniferous rocks of the West of Scotland, plutonic or volcanic rocks, referable to (at least) three periods; the last of which was separated by a long lapse of geological time from the two which preceded it.

Coal-series.—The general succession of the coal-series in Lanarkshire is illustrated by a vertical section by Mr. Ralph Moore, of which, slightly altered, the following is a synopsis:—

Upper Series, 840 feet.	*b.* Red Sandstones of Hamilton, Waddington, and Blantyre, slightly unconformable to the underlying strata (*a*), 200 feet.
	a. From the Upper Four-feet Coal downwards, with ten coal-seams from two feet and upwards in thickness; also with the "Palace Craig" and the "Airdrie" black-band ironstones.
Middle Series, 960 feet.	*b.* From the slaty black-band ironstone, down through
	a. The "Moorstone Rock," or Millstone Grit, to the Garnkirk limestone.
Lower Series, 2,200 feet.†	Six courses of marine limestone from the Garnkirk bed downwards to that which overlies the Hurlet coal. Three courses of black-band ironstone, and several beds of valuable coal.

* Address to the Geol. Section of the British Association, Dundee, 1867.

† Along the southern margin of the coal-field, and beneath the great sheets of contemporaneous trap, there occurs a remarkable series of shales and earthy limestones, described by

Mr. William Moor, in a valuable communication to the Philosophical Society of Glasgow, presents us with the following succession of the coal and iron beds of that part of the coal-field lying along the valley of the Clyde :—

Coal and Ironstone Series in the Valley of the Clyde.

Depth. Fathoms.		Thickness. Ft.	In.
42.	*Palace Craig Ironstone* (impure)		
48.	Upper Coal (good) . . .	3 to 4	6
63.	Ell Coal (good)	4 „ 8	0
67.	Pyotshaw Coal (splint) . average	4	0
68.	Main Coal (good, soft quality) .	$3\frac{1}{2}$ „ 5	0
76.	Humph Coal	1	8
81.	Splint Coal (for iron smelting) .	3	0
84.	Sour Milk Coal (variable) . .	3	0
103.	*Mushet Black-band Ironstone* .	1	4
106.	*Soft-band Ironstone* . . .	1	8
120.	*Curly Band Ironstone* . . .	0	5
127.	Virtue Well Coal . . .	2	6
132.	*Bellside Ironstone* . . .	0	7
134.	*Calderbrae Ironstone* . . .	0	8
136.	Kiltongue Coal (variable) . .	5	0
148.	Drumgray or Coxrod Coal . .	2	0
203.	*Slaty Black-band Ironstone* . .	4	6
203.	Boghead Gas Coal (1 to 20 inches)	0	10
447.	*Possil Ironstone*	1	0
467.	Lesmahago Gas Coal . . .	1	0
502.	*Govan Band Ironstone* . .	1	0
	Hurlet Coal	5	0

Mr. John Young under the name of the "Ballagan beds." They are almost unfossiliferous, and may probably be regarded as a lake deposit.—See J. Young, "Geology of the Campsie District," Trans. Geol. Soc. Glasgow, vol. i., p. 22.

Black-band Ironstones.—These valuable minerals occur chiefly in the Lower Coal and Ironstone series, the uppermost being the Airdrie band, discovered by David Musket about the beginning of the present century. It is about sixteen inches in thickness, but is nearly all wrought out.* The black-band ironstones, west of Glasgow, not unfrequently pass into coal-seams, the carbonaceous matter gradually replacing the argillaceous carbonate of iron; while less frequently they pass into clay-band ironstones.

Gas Coals.—A valuable, but thin, bed of cannel occurs to the west and south of Glasgow, amongst the upper beds of the Lower coal series, and is supposed with good reason to be identical with the Lesmahago cannel, so valuable for the production of gas. Associated with the same series are occasional beds of oil-shale.

The Boghead Gas Coal is the most remarkable of all the "Parrot coals" of Scotland for the quantity of oil and solid paraffin which it is capable of producing. It is from eighteen to twenty inches in thickness, resting on a floor of fireclay with *Stigmaria ficoides*, and overlaid by oil-shales, and occasionally black-band ironstone,

* Mr. W. Grossart "On the Upper Coal-Measures of Lanarkshire," Trans. Geol. Soc. Glasgow, vol. iii.

in which marine shells of the genera *Discina, Lingula, Conularia, Axinus,* with *Anthracoptera,* have been discovered.* Very little of this valuable bed now remains to be worked.

Dykes and Faults.—The Carboniferous district is traversed by several remarkable basaltic dykes, which range generally for miles through the country along east and west lines. They are seldom more than fifty feet wide, and traverse all formations except those of the Drift period. They sometimes coincide with faults in the strata, but in general are remarkably independent of any of the previously existing fractures, and are seldom diverted from their nearly rectilinear courses by changes in the nature of the rock. Amongst the most remarkable may be mentioned —1. That which passes by Carron, Denny, and traverses the Campsie Hills above Lennoxtown. 2. That which, commencing a little to the south-east of Linlithgow, ranges by Blackbraes to Kilsyth. 3. Another which ranges by Cumbercauld about a mile to the south of the preceding. 4. Another ranging by Torphichen and Cadder, which coincides with a line of fault with a downthrow to the south. And (5) another which ranges by Chryston, nearly parallel to the preceding. One

* Mr. Grossart, *ibid,* 107.

of these dykes is remarkably well shown in the quarries near Bishopsbridge.* The principal faults range in a similar east and west direction.

The organic contents of the Carboniferous rocks of the Clyde Basin have been very ably determined by several geologists of the district, and the results published in the Transactions of the Glasgow Geological and Philosophical Societies. A brief summary is all that can be inserted here.

Upper Series.—This series, lying above the horizon of the Slaty-band Ironstone, is characterised by molluscs of the genera *Anthracosia*, *Anthracomya*, and *Anthracoptera*; with fish of the genera *Platysomus*, *Cœlacanthus*, *Palæoniscus*, *Rhizodus*, and *Megalichthys*, all of which may be either fresh-water or brackish. But a fossiliferous band, full of undoubtedly marine genera, has recently been detected high up in this series, by Mr. Whyte Skipsey, in a position about sixty fathoms above the "Ell Coal" (see section above), taken from a colliery at Drumpeller, east of Glasgow. The following were identified: *Productus scabriculus*, *Discina nitida*, *Conularia quadrisulcata*, *Bellerophon Urii*, and

* These Dykes are clearly laid down on the maps of the Geological Survey, sheets 30, 31, and 32.

fragments of pentagonal stems of a crinoid.* The occurrence of this marine band reminds us of a similar instance which I have already described in the case of the Lancashire Coal-field.†

Lower Series.—The Carboniferous Limestone series is abundantly loaded with marine forms, of which a very full list is given by Mr. J. Young,‡ for the Campsie district, of which the following is a selection:—

Echinoderms.—Archæocidaris Urii, Actinocrinus.

Annelids.—Spirorbis carbonarius, Serpulites carbonarius.

Crustacea.—Bairdia Hisingeri, Beyrichia arcuata, Cythere ventricornis.

Polyzoa.—Ceriopora interporosa, Fenestella plebeia.

Brachiopoda.—Athyris ambigua, Chonetes Hardrensis, Crania quadrata, Discina nitida, Lingula mytiloides, L. squamiformis, Orthis Michelini, Productus aculeatus, P. cora, P. costatus, P. Martini, P. reticulatus, P. Youngianus, Rhynchonella pleurodon, Spirifera bisulcata, S. glabra, Strophomena deleta var. analoga, Terebratula hastata.

Lamellibranchs.—Aviculo-pecten arenosus, A. fimbriatus, A. granosus, Pecten Sowerbii, Pteronites fluctuosus. Arca reticulata, Cardiomorpha oblonga, Cypricardia cylindrica, Leda attenuata, Modiola elongata, Myalina crassa, Nucula lineata.

Gasteropods.—Dentalium priscum, Euomphalus acutus, E. pentangulatus, Macrocheilus acutus, Murchisonia striatula, Pleurotomaria monilifera, P. conica.

Heteropods.—Bellerophon decussatus, B. Oldhamii.

* Trans. Geol. Soc. Glasgow, vol. ii., part 1, p. 52.

† See p. 206.

‡ *Ibid*, vol. i., part 1, p. 53.

Cephalopods.—Cyrtoceras unguis, Goniatites excavatus, G. Gilbertsoni, G. striatus, Nautilus biangulatus, N. subsulcatus, Orthoceras attenuatum, O. cinctum, O. undatum.

Fishes.—Amblypterus punctatus, Cladodus mirabilis, Cochliodus magnus, Helodus lævissimus, Megalichthys Hibberti, Palæoniscus Robsoni, Petalodus Hastingsiæ, Pœcilodus obliquus, Rhizodus Hibberti, Rhizodopsis minor.

CHAPTER XXIV.

COAL-FIELDS OF MID-LOTHIAN AND HADDINGTON.

These coal-fields consist of a double trough, the deeper of which lies in Edinburghshire on the west, and the shallower in Haddington on the east.

The western boundary is the Pentland Hills, along the base of which the Carboniferous strata plunge rapidly towards the centre of the trough. The axis of the trough lies nearly north and south, passing by Dalkeith. On approaching the Carberry ridge, the beds again rise and crop out, and the Roman Camp limestone forms a ridge dividing the two troughs. On the east of the Carberry ridge the lower coal-seams again roll in, and form the wide trough of Haddington, where the beds lie in a position not much removed from the horizontal, and having Tranent as a centre.

To the north of these troughs, the coal-seams strike out to sea, are overspread by the Frith of

Forth, and reappear on the opposite coast of Fifeshire.

The thickness of the Coal-series in the Lothians is, according to Mr. Milne, upwards of 1,000 fathoms, consisting of sandstone 286 fathoms, of shales 188, of limestone 27, of clay 12, and of coal 21 fathoms. There are from 50 to 60 coal-seams of greater thickness than one foot, the thickest being 13 feet.

My colleague, Mr. Howell, arranges the Coal-series into three groups, of which the total thickness is 3,150 feet. This does not include the Calciferous Sandstone series, which contains very little workable coal,* but is characterised by the presence of great beds and sheets of contemporaneous and intrusive trap, which are ably described by Messrs. Howell and Geikie.† The Coal-measures are confined exclusively to the Mid-Lothian trough, and do not occur in Haddington. The faults generally range from east to west, transversely to the axis of the troughs.

The workable coal-area, as measured from the maps of the Geological Survey, is 64 square miles.

* The Houston coal—about two feet thick—of Linlithgowshire, is one of the few workable seams.

† "The Geology of Edinburgh." (Mem. Geol. Survey.)

Coal-seams of Mid-Lothian.

(Taken from the centre of the trough near Dalkeith.)

Coal-Measures, 1,220 *feet.*

	Ft.	In.
Sandstone and Shale	346	0
Clay Knowes Coal	3	6
Splint Coal	3	10
Beefie Coal	3	6
Jewell Coal	4	0
Coal	2	8
Cowpits Little Splint	2	2
Cowpits Five-feet	5	6
Glass Coal	2	0
Barrs Coal	4	0
Cowpits Three-feet	3	0
,, Six-feet	4	6
Millstone Grit	340	0

Lower Coal-Series, 1,590 *feet.*

Cowden Deception Coal	2	2
,, Cryne	2	6
,, Mavis	2	8
,, Great Seam	8	0
,, Diamond	2	7
,, Lilla Willie	5	1
,, Blackbird Seam	3	11
,, Coronation	3	10
,, Hard Splint	3	3
,, Smithy Coal	2	9
,, Bryant's Splint	5	8
,, Aleck's Coal	2	7
,, Coal	2	6
,, Little Splint	2	1
Cowden Coal	2	1
,, Parrot Seam	3	0
,, Chalkieside Lime Coal	3	0

The above include only coals of 2 feet and upward. There are altogether no less than 46 seams with an aggregate thickness of 122 feet of coal. There are also 9 seams of ironstone of 2 inches and upward.

The principal coals are "the Great Seam," which has been traced from its outcrop at Gilmerton, under the valley of the Esk, over the Carberry ridge, to the valley of the Tyne, a distance of 12 miles. It extends from the flanks of the Lammermuir range northward to the sea. Below this, at a depth of 250 fathoms, is the "North Greens" coal, which yields the "Parrot-coal," valuable for its gas.

The East Lothian Coal-field.—The area of this coal-field is about 30 square miles, and the strata of which it is composed belong exclusively to the Lower Coal and Ironstone series, the seams of coal and ironstone which are wrought in it being the equivalents of the "edge coals" of Mid-Lothian, some of which can be individually identified. The following is the series as given by Mr. Howell:*—

* Geology of the East Lothian Coal-field, by Messrs. Howell, Geikie, and Young, Mem. Geol. Survey, 1866.

Coal-series of East Lothian.

		Ft.	In.
Coal "Great Seam"	. . . . .	7	0
Strata	. . . .	50	0
Splint Coal	. . . . . .	4	0
Strata	. . . . from 7-ft. to	18	0
Parrot Coal	. . . . . .	1	8
Strata	. . . . from 7-ft. to	34	0
Three-foot Coal	. . . . .	2	6
Strata	. . . .	9	0
Four-foot Coal	. from 3-ft. 8-in. to	4	11
Strata	. . . .	118	0
Five-foot Coal	. . . . .	4	0
Strata, with black-band Ironstone — about		130	0
Panwood Coal	. . . . .	1	6
Strata	. . . .	72	0
Splint and Rough Coals (16 feet apart)	.	4	0
Strata	. . . .	100	0
Haughielin Coals (sometimes "Parrot" Coal)	. . . . 16-in. to	1	6
Strata	. . . .	35	0

Lower Limestone Group.—The basis of the above series is the Lower Limestone group, consisting of three principal beds of limestone, separated by intervening strata of sandstone and shale, with one seam of coal of about one foot in thickness. These three limestones form a broad zone encircling the East Lothian coal-field on the east and south-east, and dividing it from the Mid-Lothian coal-trough on the west.

Underneath these occur the Calciferous Sand-

stones, with beds of volcanic ashes and contemporaneous igneous rocks, and also including the celebrated Burdie House, or Queensferry, Limestone, remarkable for the varied character of its fauna, which includes numerous genera of fish, small crustacea, and plants.*

* For a list of fossils of the Burdie House Limestone, see "Geology of Edinburgh," Mem. Geol. Survey, p. 37.

CHAPTER XXV.

FIFESHIRE COAL-FIELD.

This coal-field is of considerable extent and of great mineral productiveness, but is over a large part of its eastern area much dislocated by faults, and damaged by the intrusion of igneous rocks. Nearly the whole of the coal-seams enter the sea between Kirkcaldy and East Wemyss, and present the following section as given by Mr. Landale in his valuable memoir:—

Coal-seams of Fifeshire.

	Ft.	In.		Ft.	In.
1. Parrot Seam	2	6	17. Borcland Coal	3	6
2. Pilkembare Coal ...	2	0	18. Sand Well	3	0
3. Wall	3	0	19. Dysart Main Seam ...	21	0
4. Barn Craig	5	6	20. Dysart Lower Seam ...	7	0
5. Upper Coxtool Coal ...	3	0	21. Dunniker Five - feet Coal	2	6
6. Lower " " ...	3	6			
7. Den Coal	2	2	22. Four-feet Coal ...	4	0
8. Main or Chemis ...	9	0	23. Three-feet „	3	0
9. Bush Coal	3	6	24. Black and Parrot Coal	5	3
10. Parrot „	2	3	25. Upper Smithy	3	0
11. Wood „	3	0	26. Lower " " ..	1	6
12. Earl's Parrot Coal ...	2	0	27. Parrot Seam Coal ...	2	0
13. Bowhouse " ...	6	6	28. Coal Seam	2	4
14. Brankston " ...	4	0	29. Invertiel Coal	5	6
15. Coal More " ...	2	6			
16. Coal Mangey „ ...	2	6	Total thickness of Coal	120	6

* Transactions of the Highland Society, vol. xii.

The Invertiel coal overlies a thick and very constant bed of limestone which forms the physical base of the coal-producing strata. Underneath this limestone is a thick series of Lower Carboniferous rocks, the coal-seams of which are not of economical value, but which give evidence of volcanic activity throughout a period ranging from the Calciferous Sandstone up through the Carboniferous Limestone. The necks of many of the old submarine volcanoes which poured forth molten lava over the sea-bed, or vomited forth showers of ashes, stones, and blocks, can even now be identified, and appear as isolated bosses of basalt, tuff, and agglomerate; as some of these invade the Coal-measures of Fifeshire, it is not improbable they are referable to the Permian period.*

This coal-field contains excellent coal for gas, steam, and iron-smelting purposes, together with smithy coal, and some anthracite.

Clackmannan Coal-field.

This coal-field is separated from that of Fife by the uprising of the Lower Carboniferous rocks near Dunfermline. It stretches along the northern and eastern banks of the river

* Prof. Geikie, Address Brit. Assoc., Dundee, 1867.

Forth, by which it is separated from the great central coal-field of the Clyde Basin.

According to Mr. Geddes, the southern portion of this coal-field is much exhausted; the middle area is extensively worked, the northern portion is comparatively entire north of the river Devon; these three divisions are separated by considerable faults. The following is the series of the coals in descending order at Old Sauchie:*

	Ft.	In.		Ft.	In.
1. Coal	2	6	7. Mosie Coal	2	0
2. Three-feet Coal	3	0	8. Lower five-feet Coal ...	5	0
3. Upper five-feet	5	0	9. Splint Coal	2	9
4. Four-feet Coal	4	0	10. Coalsnaughton... ...	4	6
5. Nine-feet Coal	9	0			
6. M'Nish Coal	2	9	Thickness of Coal	40	6

* Mr. Geddes, Coal-Commission Report, vol. i., p. 76.

CHAPTER XXVI.

AYRSHIRE COAL-FIELD.

The Ayrshire coal-field stretches along the coast from Ardrossan to the mouth of the river Doon, and extends inwards to the base of the hills of trappean rocks, by which it is separated from the coal-field of the Clyde Basin. It is a rich and productive district, large quantities of coal being shipped from Ayr, Troon, Irvine, and Ardrossan.

The Carboniferous rocks rest unconformably on the older formations, while they are in turn overlaid uncomformably by rocks of Permian age in consequence of this, the true base and upper limit of the series can nowhere be seen.* The following is the general succession of the beds in descending order:—

* "Ayrshire (Southern District)," Mem. Geol. Survey of Scotland (1869), p. 15.

GROUPS OF STRATA.	LOCALITIES.
Coal-measures.—(*b*)Red sandstones, fireclays, and marls, with Carboniferous plants, and a seam of limestone, with *Spirorbis.* No workable coals. (*a*) A thick series of white and grey sandstones, dark shales, fireclays, ironstones, and coal-seams.	Monkton, Aunbank, Coylton Water below Coylton, Ravines of the Ayr at Catrine, Coal-fields of Ayr, Coylton, Dalmellington, Cumnock, Auchenleck, Lugar, and Sorn.
Lower Coal and Ironstone series.—Sandstones, shales, and limestones, with seams of coal and ironstone.*	Girvan Coal-field, Craigs of Kyle, Kiers, Sorn, etc.
Calciferous Sandstone series.—Upper beds of white sandstones, cement stones and marls, below which are red sandstones, marls, and cornstones.	Dailly, the coast from the mouth of the Doon to Brackenbrae.

The following is the order of succession and average thickness of the principal coals in the Ayr district :—

* In the south of Ayrshire this series is but poorly represented, but northward it thickens out, and produces several seams of workable coal. The Dalry black-band ironstone belongs to this part of the series.—Mr. J. Geikie, "Carboniferous Formation of Scotland," p. 12.

Red Sandstone Series.

		Ft.	In.
Light sandstones, shales, fireclays, and thin coal	60-ft. to	70	0
Ell coal		3	4
Strata		78	0
Crawfordston Coal		8	0
Strata	30-ft. to	60	0
Ayr, Soft, or *Five-feet Coal*	5-ft. to	7	0
Strata		150	0
Ayr, Hard, or Splint Coal		4	0
Strata		300	0
Black-band Ironstone		1	0
Strata		120	0
Uppermost Limestone.		10	0

In the Dalmellington coal-field we find the following series :—

Craigmack Black-band Ironstone	0	10
Strata	282	0
Lillyhole Coal	5	6
Strata	350	0
Chalmerston Coal	4	0
Strata	60	0
Minnevey Coal	3	6
Strata *	654	0
Burnfoot Black-band	2	3

Igneous Rocks.—Besides the great beds of contemporaneous felstones, porphyrites, and melaphyres with volcanic ashes of the Lower

* In these beds, Mr. Geddes mentions the "Sloanston," "Camlarg," and "New" Coals, all of which are three feet and upwards in thickness.

Carboniferous period, which rise into the Dunlop Hills, and separate the Ayrshire coal-field from that of the Clyde-Basin, there are frequent intrusive sheets and vertical dykes of dolerite and basalt, which have destroyed much of the valuable minerals, and greatly interfere with the successful prosecution of mining operations. The Permian rocks which overlie the Coal-measures near the centre of the coal-field, are also underlaid by beds of porphyrite, melaphyre, and tuffs, which are referable, according to the views of the Government Surveyors, to the Permian period itself.

Sanquhar Coal-basin.—A small detached coal-field lies along the valley of the Nith for a distance of five miles, near the centre of which is the village of Kirkconnel. Along the N.E. and N.W. it is bounded by faults, bringing to the surface the Silurian Grits and Old Red Sandstone; in the opposite directions the Coal-measures rest directly upon the Lower Silurian beds, the Lower Carboniferous series being absent.*

It contains several seams of coal, which are as follows :—

* Map of the Geol. Survey, Sheet 15.

*Coal-seams.**

	Ft.	In.
Upper, or Creepy Coal	2	8
Main Coal	3	6
Wee ,, ...	1	10
Dauch ,, ...	3	8
Drumbowie Coal	4	9
New Coal	1	0
	18	3

* As stated by Mr. Geddes. Rep. Coal Commission, vol. i., p. 75.

CHAPTER XXVII.

OTHER COAL-FIELDS OF SCOTLAND.

Lesmahago Coal-Basin.

To the south of the general tract of the Lanarkshire coal-field lies the detached basin of Lesmahago and Douglas, consisting of Carboniferous rocks, resting unconformably upon, and nearly surrounded by, beds of the Lower Old Red Sandstone. The strata themselves belong to the Lower coal-series, and are distributed along the valleys of the Nethan and the Ayre. The celebrated gas coal is considered to be on the same geological horizon as that of the western vicinity of Glasgow, which is known to lie well down in the same series. The following are sections of the strata curtailed from those of Dr. Slimon:*—

* From Appendix to Sir R. Murchison's paper on the "Lesmahago Silurians," in Journ. Geol. Soc., vol. xii., p. 25. The geological features of this district are also described by

Section at Coal Burn.

	Ft.	In.
Shale and Limestone ...	10	0
Sandstone and Shale ...	27	0
Gas and Dross Coal ...	1	0
Sandstones and Shales ...	25	0
Dross Coal	3	0
Fire-clay	0	11
Dross Coal, with six inches of Horn Coal	3	11
Strata	13	0
Coal	3	0
Fire-clay	3	6
Coal	2	9
Strata	12	0
Black-band Ironstone ...	0	8
Shales with Ironstone ...	7	4
Smithy Coal	1	6
Fire-clay	1	6
Coal	4	0
Stone...	0	7
Coal	4	7
Shales, with seams of Ironstone	81	8
Coal, with 6 inches of stone	6	0
Strata, with Ironstone ...	54	0
Coal (stinking)	5	0
Sandstones and Shales ...	34	0
Limestone	1	8
Grey Shale	20	0
Ironstone	0	8
Shale and Limestone with *Productus*	46	0
Sandstone and Limestone resting on upper Old Red Sandstone ...		

Section at Auchenheath.

	Ft.	In.
Shales and Sandstones.		
Limestone	1	6
Shale	10	0
Strata, with four beds of Limestone	225	3
Smithy Coal	1	4
Shelly Clay	1	6
Coal	4	0
Strata	15	0
Gas Coal	0	10
Black-band Ironstone ...	0	5
Shales with Ironstone balls	3	8
Coal	0	8
Fire-clay	1	6
Dross Coal	3	0
Shales and Sandstones ...	54	6
Coal	0	10
Shale	5	0
Gas Coal	1	9
Ironstone	0	4
Fire-clay	1	3
Coal	0	6
Sandstone resting upon Limestone.		

These beds are supposed to rest upon Old Red Sandstone.

This coal-tract is about 7½ miles from E. to W., and from N. to S. Mr. J. Ferguson states that three-fourths of its area is stored with coal of second class quality. There is at Ponfrich an aggregate thickness of 53 feet within a vertical depth of 200 fathoms.

Mr. Geikie, "On the Old Red Sandstone of the South of Scotland," *ibid*, vol. xvi., p. 314.

CANOBIE COAL-FIELD, DUMFRIESSHIRE.

The small but valuable tract of Carboniferous rocks known as "the Canobie Coal-field," lies in the depression formed by Eskdale and Liddesdale, on the borders of the Cheviots. The beds repose on those of Lower Carboniferous age, and are overlaid by others of Permian age; and along the north-west and south-east the coal-field is bounded by faults. The general dip of the strata is southwards, and it seems not improbable that the coal strata are but the northern outcrop of a more extensive tract which lies concealed beneath newer formations towards the head of the Solway Firth.*

The following are the coal-seams of the Canobie district:—

Canobie.

	Ft.	In.
Three-feet Coal	3	4
Six-feet "	6	0
Nine-feet "	9	0
Steam "	3	0
Five-feet "	5	0
Blast-top "	4	6
Seven-feet "	6	0
	36	10

* Coal Commission Rep., vol. i., p. 77.

Mr. Geddes states that the 3-feet and 6-feet seams of Canobie are already exhausted; but considers that the Byreburn coals may be expected to underlie those of Canobie, in which case 14 millions of tons would be added to the known supply.

Argyleshire.—The parish of Campbelton contains a little coal-field, situated amongst metamorphic schists. For nearly a century coal has been worked on a limited scale, and, according to Mr. Geddes, three seams are known at Drumlemble, viz.: 3, cannel or gas coal, from 18 to 30 inches in thickness; 2, the main coal, 4 to 6 feet; 1, underfoot coal, from 2 to 3 feet. Other seams may possibly exist in that district.

BRORA COAL-FIELD, SUTHERLANDSHIRE.

A small coal-field occurs at Brora, near the shores of Dornoch Firth. It has been shown by Sir R. Murchison to be of the age of the Lower Oolite, and in all probability contemporaneous with the carbonaceous strata of Whitby in Yorkshire.* The following is part of the section of one of the pits from which the coal was extracted:—

* Trans. Geol. Soc. Lond., vol. ii., 2nd Series, p. 393.

	Ft.	In.
13. Dark argillaceous schistus, with soft partings and a few shells . .	36	6
14. Very large-grained sandstone, with shells and wood (coal-roof) . .	5	0
15. Fine cubical coal, burning to white ash	3	8
16. Bituminous shale, containing natural oil; burns, but does not consume . .	2	0
17. Slate-coal with pyrites	1	4
18. Fire-clay and argillaceous schistus .	90	0

The coal-bed appears to be at, or near, the base of the Great Oolite, as in Yorkshire; but the Inferior Oolite would appear to be absent, if the thick bed of shale belongs (as is probable) to the Upper Lias. The shells enumerated by Sir R. Murchison from the beds above the coal, are typical of the formations from the Great Oolite to the Calcareous Grit.

The first pit was opened in 1598 by the Countess of Sutherland. That formerly in use was sunk in 1814, and up to the year 1827 seventy millions of tons of coal had been raised. The works were discontinued in 1832.

Skye.—In the Isle of Skye is a small coal-field, probably of Lower Oolitic age, which contains a bed of coal nearly 5 feet in thickness.

Resources of the Coal-fields of Scotland.

The estimates of the available quantity of coal in the coal-fields of Scotland have been drawn up

for the Royal Coal-Commission by Mr. John Geddes, one of the commissioners; and to no one could the task have been more worthily entrusted, as Mr. Geddes's long experience as a mineral engineer had given him opportunities of becoming acquainted with the details of the Scottish coal-fields, which were of the highest value to this inquiry. The estimate produced by Mr. Geddes of the coal-resources is, I find, much below that arrived at by myself in 1858; but I have no hesitation in substituting it for my own, which had little pretensions to accuracy; as the means at my disposal for obtaining the details necessary for such a calculation were very imperfect.

Distributing the coal-fields into counties, Mr. Geddes gives the following quantities of available coal for each, the whole of which is included within a vertical limit of 3,000 feet:—

County	Available coal in tons.
1. Edinburgh	2,153,703,360
2. Lanark	2,044,090,216
3. Fife	1,098,402,895
4. Ayr	1,785,397,089
5. East Lothian	86,849,880
6. Firth of Forth	1,800,000,000
7. Dumfries	358,173,995
8. West Lothian	127,621,800
9. Stirling	106,475,436

County.	Available coal in tons.
10. Clackmannan	87,563,494
11. Perth	109,895,040
12. Dumbarton	48,618,320
13. Renfrew	25,881,285
14. Argyle	7,223,120
15. Sutherland	3,500,000
16. Roxburgh	70,000
Total . . .	9,843,465,930

Deduct from above 200,000,000 tons for the quantity since worked out, and there remain in 1880 for future use (about) 9,643,000,000 tons.

The produce of the Scottish coal-fields is rapidly increasing. In 1859 it was 10,300,000 tons; in 1878 it had risen to 17,837,282 tons from 534 collieries.* In the same year 902,000 tons of pig iron were smelted in 94 blast furnaces from clay-band and black-band ironstones.

* Returns made by the Inspectors of Collieries, and published in the "Mineral Statistics," 1878.

CHAPTER XXVIII.

CARBONIFEROUS ROCKS OF IRELAND.

A LARGE portion of the centre and south-west of Ireland is occupied by Carboniferous Limestone, upon which at intervals repose higher strata productive of coal, and forming isolated coal-fields. The existence of these outliers, as well as analogy with British geology, leads to the conclusion that, at the close of the Carboniferous Period, large tracts of coal-bearing strata existed over Ireland, which have since, to a great extent, been removed by denudation.*

Anthraciferous and Bituminous Districts.—If we group the coal-fields south of a central line drawn from Galway Bay to Dublin Bay, into one series, and those north of this line into another, we have the following specialities in reference to each.

1. *The Southern Group.*—All the coal in the

* On this subject, see the Author's "Physical Geography of Ireland," p. 150 (1878).

district of this group is anthracite, and this statement is true with reference to the coal of Clare, Limerick, Cork, Tipperary, Queen's County, Kilkenny, and Carlow.

2. *The Northern Group.*—On the other hand, the coal in this district is bituminous; and this statement holds good with respect to the Arigna (Connaught), Tyrone, and Ballycastle coal-fields; while the general succession of the strata above the Carboniferous Limestone bears a closer analogy to that of England than in the case of the southern coal-districts.

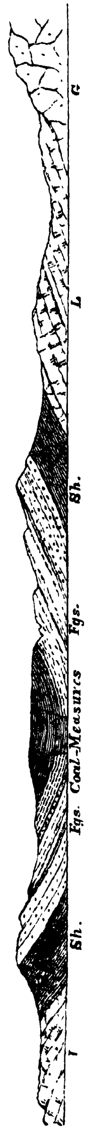


Fig. 17.—SECTION ACROSS THE CASTLECOMER COAL-FIELD.

G Granite. L Carboniferous Limestone. Sh. Shale series. Figs. Flagstones.

SOUTHERN DISTRICT.

General Succession of the Beds.

The general succession of the strata is similar over this whole region, which has been surveyed and described by the Government Surveyors.* Upon a general basis

* In several "Explanations" to accompany the Geological Survey Maps by the late

of Carboniferous Limestone, there reposes a series of dark fossiliferous shales, which are overlaid by flagstones, upon which rest shales and sandstones with beds of coal. The shales and flagstones which rest upon the Limestone, I regard as the representatives of the Yoredale beds and Millstone Grit of England; and the overlying Coal-measures as the equivalents of the Lower, and a part of the Middle, Coal-measures of the same country.* This series is illustrated by the section (Fig. 17) of the Castlecomer coal-field; and is more fully described in the following table of strata taken in the S.W. and S.E. of Ireland, in descending order :—

NAME OF FORMATION.	NATURE OF STRATA.	
	Co. Kilkenny, etc.	Co. Clare, etc.
Millstone Grit ...	b. *Flagstone series.* Grits and excellent flagstones with shales, about 650 feet, passing downwards into sandy shales, with annelid tracks.	b. Flagstones chiefly worked at Ballynacally; Annelid tracts not common

Messrs. Jukes and Foote, and Messrs. Kinahan and O'Kelly with Palæontological Notes by Mr. W. H. Baily.

* Explanation of sheets 136 and 137 of the maps of th Geological Survey of Ireland.

NAME OF FORMATION.	NATURE OF STRATA.	
Yoredale Beds ...	a. *Black Shale series.* Sandy shales passing downwards into dark laminated shales, full of marine fossils, *Goniatites Bellerophon, Euomphalus, Aviculo-pecten*, etc.	a. *Shale series.*—Black, grey, and olive shales, sometimes arenaceous, spheroidal — with numerous fossils—*Goniatites crenistria, Orthoceras, Posidonomya vetusta, Aviculo-pecten papyraceus, Loxonema Galvani* (Baily), etc.
Carboniferous Limestone ...	*Upper Limestone*, forming the basis of the series.	*Upper Limestone.*

Clare, Limerick, and Cork.—This district is very extensive, stretching over a considerable tract both to the north and south of the estuary of the Shannon, but is only locally productive of coal. Mr. Weaver, who described this district many years since, truly states that the seams are few in number and importance; that they are frequently thrown into high inclinations, and while in some places compressed to a few inches, in others they are swollen out to several feet.* The most important district is

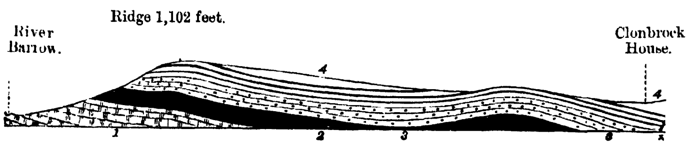
* Trans. Geol. Soc. Lond., vol. v. See also "Explanation" to Sheet 142, by Messrs. Kinahan and Foote, Mem. Geol. Survey.

situated between the River Blackwater and Kanturk, where coal has been extensively worked.

Queen's County, Kilkenny, and Tipperary.

This coal-field is the most important economically in the South of Ireland, and may be designated "The Leinster Coal-field," though a considerable spur strikes southward into Tipperary. The northern portion has a generally basin-like structure, and occupies a table-land overlooking the plain of Carboniferous Limestone by which it is encircled, and upon which it rests. This will be apparent from the following section, reduced from that of the Geological Survey:*—

Fig. 18.—SECTION ACROSS THE EASTERN PORTION OF THE LEINSTER COAL-FIELD BY BILBOA COLLIERY.



1. Carboniferous Limestone. 2. Black Shale Series.
3. Flagstone Series. 4. Coal Measures.

Descending Series of the Castlecomer and Killenaule Coal-fields.

(Upper Coal-measures.—Absent; probably owing to denudation).

* "Explanation" to Sheet 137, by Messrs. Jukes and Kinahan.

Fresh-water or Estuarine.

MIDDLE COAL-MEASURES (Jarrow Series).—Sandstones, shales, etc., with several coal-seams from the "Jarrow Coal" upwards.

FOSSILS.—*Anthracosia* (*Unio*), *Myalina;* Crustacea, Reptilia, etc.

Marine Series.

LOWER COAL-MEASURES, or "GANNISTER BEDS."—Grits, shales, and two or three thin seams of coal, with roofs containing marine shells.

FOSSILS.—*Phillipsia*, *Bellinurus regina* (Baily), *Goniatites*, *Bellerophon*, *Aviculo-pecten*, and many others recently discovered.

FLAGSTONE SERIES (representing Millstone Grit Series).—Beds of rippled micaceous flagstones and shales.

FOSSILS.—Chiefly tracks of marine Annelids or of Molluscs.*

SHALE SERIES (representing the Yoredale Beds.)—Grey sandy shales, passing downwards into dark shales, with earthy limestones.

FOSSILS.—*Goniatites sphæricus*, *Bellerophon*, *Euomphalus*. *Aviculo-pecten papyraceus*, *Posidonomya Becheri*, *P. membranacea*, etc.

CARBONIFEROUS LIMESTONE.—(*a*) Upper Limestone (with beds of chert), coralline; (*b*) Middle Limestone or "Calp" beds, carbonaceous shales and earthy limestones; (*c*) Lower Limestone, compact limestone, often dolomitic.

Total thickness, 1700 ft.

The following is the general series of coals in the Castlecomer coal-basin, by Messrs. Jukes and Kinahan, somewhat modified :—

	Ft.	In.
Uppermost beds, about	12	0
6. *Peacock Coal*	1	10

* W. H. Baily, Explanation of sheet 128 of the maps of the Geological Survey, p. 15.

	Ft.	In.
Strata	45	0
5. *Stony Coal*	3	0
Strata	21	0
4. *Double Seam*	5	0
Strata and shales with *Myacites* (Anthracosia ?)	120	0
3. *Three-feet* or *Old Colliery Coal* . .	3	0
Strata	180	0
2. *Four-foot Coal* . . . 1ft. 6in. to	3	6
Strata	300	0
1. Upper and Lower *Towlerton Coals* 1ft. 6in. to	2	0
Flag Series, about	650	0
Black Shale Series	500	0
Upper Carboniferous Limestone.		

The Upper Towlerton seam is of good quality, about twenty inches in average thickness, and known elsewhere as the *Skehana* or *Wolfhill* coal. As shown by the marine fossils which occur in the neighbourhood of the Towlerton coals, they may be regarded as the representatives of the "Gannister Coals" of England. One of them has a floor which might be mistaken for that of the Gannister Coal of Yorkshire. The following is the remarkable series of fossils from the Gannister beds, first discovered byMr. Aher of Castlecomer, and afterwards collected by Mr. Hardman and Mr. Baily, F.G.S., who has determined their species. They are in all 16 genera and 19 species of marine forms.*

* Hull, Quart. Journ. Geol. Soc., Nov., 1877, p. 621.

Fossils from the Lower Coal-measures of Castlecomer.

CRUSTACEA... ...	Phillipsia pustulata (*Schloth.*, sp.) Leperditia Okeni? (*Münst.*, sp.)
CEPHALOPODS ...	Goniatites fasciculatus (*M'Coy*). —— crenistria (*Phil.*) Nautilus (like cyclostomus, *Phil.*) Orthoceras Steinhaueri (*Sow.*)
GASTEROPODS ...	Euomphalus (sp. inc.)
LAMELLIBRANCHS .	Aviculo-pecten (Lima) alternatus (*M'Coy*). —— granosus ? Axinus (sp. inc.) Edmondia (small sp.) Pullastra bistriata (*Portl.*) —— scalaris (*M'Coy*).
BRACHIOPODS ...	Athyris planosculata (*Phil.*) Orthis resupinata (*Mart.*) Productus semireticulatus (*Mart.*) Rhynchonella pleurodon (*Phil.*) Spirifer pinguis (*Sow.*), *or* trigonalis.
CRINOIDS	Actinocrinus (joints of, abundant).

CHAPTER XXIX.

NORTHERN GROUP OF IRISH COAL-FIELDS.

Leitrim Coal-fields (Connaught).—These coal-fields form several detached table-lands, or eminences, on both sides of Lough Allen, rising into elevations from 1,000 to 1,377 feet above the surrounding districts, formed for the most part of Carboniferous Limestone. Those to the west of the Lough are the most important, and form two small isolated basins to the north and south of the River Arigna; owing to which they are sometimes called the "Arigna Coal-fields." Of this district excellent descriptions have been drawn up by Sir R. Griffith,* Sir R. Kane,† and the late Mr. Du Noyer,‡ and more recently by Mr. Cruise of the Geological Survey of Ireland, who has just completed a detailed survey of the dis-

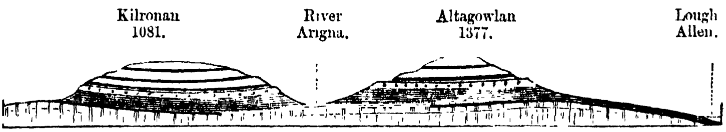
* Report on the Connaught Coal-fields (Arigna District), presented to the Royal Dublin Society, 1818.

† "Industrial Resources of Ireland," 2nd edit.

‡ "On the Bituminous Coal of the Arigna District," by G. V. Du Noyer (*Geologist Magazine*, March, 1863), with Map and Sections.

trict, which enables us to form an accurate judgment of its structure and resources.* The following section, reduced from one by Mr. Du Noyer, gives a good idea of the relations of these coal-tracts, and their disseverance by denudation:—

Fig. 19.—SECTION ACROSS THE LEITRIM COAL-FIELDS.



Coal Measures, Millstone Grit, and Limestone Shale, resting on a base of Carboniferous Limestone.

General Succession of the Beds.—In this district the Millstone Grit and Yoredale beds are well developed, and interposed between the Carboniferous Limestone and Coal-measures. The former rises into fine escarpments, which, at the mountain called Cuilceagh, on the borders of Fermanagh, reaches an elevation of 2,188 feet, and exhibits a fine mural cliff similar to those of the Millstone Grit of Kinder Scout, in Derbyshire.†

* Explan. Memoir to Sheets 66 and 67 (1878).

† This district was examined by the Author during a visit to the Earl of Enniskillen, in 1870. Here a thick series of sandstones intervenes between the limestone and overlying shales.

The Coal-seams belong to the Lower Coal-measures exclusively, as shown by the marine fossils they contain (*Goniatites*, etc.); the Middle and Upper Measures having been denuded away. The Yoredale Shales, which underlie the Grit, are rich in clay-ironstones and cement-stones, containing *Goniatites* and other marine shells.

Carboniferous series at Kilronan.

			Ft.	In.
Coal Measures, 286 to 453 feet.	Sandstones and flags		110	0
	Shale, with numerous bands of clay-ironstone (fossil shells)	100 to	200	9
	Coal. Third seam		0	9
	White sandstone	24 to	45	0
	Gray soft clay—Coal-roof	10 to	15	0
	Coal. Second seam		2	6
	Sandstone and shale	22 to	30	0
	Coal. First seam, mixed with shale	1 to	3	0
	Sandstones and shales	17 to	36	0
Millstone Grit, 60 to 250 ft.	Massive coarse sandstone	60 to	250	0
Yoredale Beds, 600 ft.	Black shales and grey flags; nodular layers of ironstone (fossiliferous)	600 to	1000	0
Carboniferous Limestone.	Upper, middle, and lower limestone.			

Details.—The coal of this district is bituminous. In the Aghabehy coal-basin, there is but one seam of much value, called the "top seam" (the second in the above list). It has a shale

roof and sandstone floor, and averages 18 inches in thickness. The middle coal of the Altagowlan basin has a similar roof and floor, and the same thickness, and the upper seam is of equal thickness with the lower. The following analysis of the Aghabehy coal has been published by Sir R. Kane:*—

Volatile matter	23·10
Pure Coke	66·15
Ashes	10·75
	100·00

Ironstones.—The clay-ironstones which occur both amongst the shales of the Coal-measures, and especially amongst those of the Yoredale-beds below, are intrinsically valuable from their quantity and richness in iron. They were formerly smelted at the Arigna iron-works on the shores of Lough Allen, and it is to be hoped will again be turned to account. The following analysis by Sir R. Kane will show their average composition:—

Protoxide of iron	51·36
Lime	1·59
Magnesia	1·92
Alumina	0·98
Insoluble clay	12·82
Carbonic acid	31·33
	100·00

Proportion of metallic iron, 40 per cent.

* "Industrial Resources," 2nd edit., p. 23.

The Tyrone Coal-field (Ulster).

This coal-field is unquestionably one of great economic importance, containing as it does large quantities of bituminous coal, placed within easy reach of the manufacturing districts of the North of Ireland. It lies to the north of the town of Dungannon, and in its centre is the village of Coal-Island, where the Ulster Canal places the district in connection with Lough Neagh.

In structure the Coal-island district is a basin, along the western portion of which the coal-seams crop out and have been worked, but which is overlaid and concealed beneath New Red Sandstone and Marl over probably two-thirds of its entire area to the eastward; hitherto the coals have scarcely been disturbed under this large district;* but I have come to the conclusion that it stretches to within a short distance of the shores of Lough Neagh under the newer formations.

From the survey of Sir R. Griffith, it would

* Except in two or three cases, coal-mining has been carried on in a very rude and unsystematic manner in this district, which ought to be the great coal-store for the North of Ireland. The Geological Surveyors have recently completed a detailed survey; and a valuable Memoir has been prepared by Mr. Hardman on the structure of this coal-field (1877).

appear that the Tyrone coal-field is rich in minerals, though of limited extent. Along the banks of the river Torrent seven workable beds of coal appear, having a combined thickness of 30 feet, and included within 280 yards of strata, which are ultimately covered over by Triassic strata* (Fig. 20).

The general succession of the strata, as stated by Mr. Hardman, is as follows: †—

	Ft.
1. *Trias or New Red Sandstone and Marl*, which rest unconformably on the Coal-measures at Coalisland .	
2. *Middle Coal-measures.*—Soft sandstones, shales, and fireclays, with ironstones and coal-seams . .	930
3 *Lower Coal-measures* (*Gannister Beds*). Hard sandstones and grits, slaty shales with a few coal-	

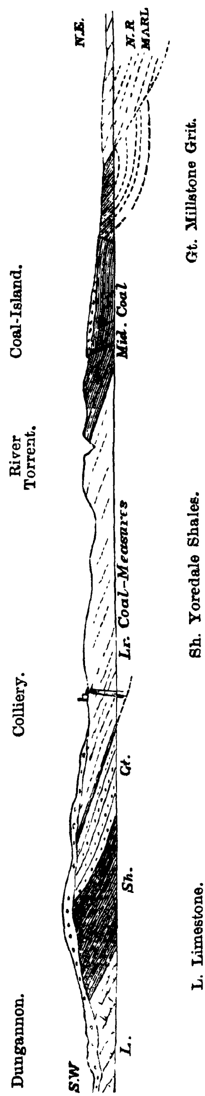


Fig. 20. SECTION ACROSS THE TYRONE COAL-FIELD.

* Geological and Mining Surveys of Tyrone and Antrim. Dublin, 1829.

† Explan. Mem. Sheet 35, p. 10. The fossils are enumerated and described by Mr. Baily. *Ibid.*, p. 14.

	Ft.
seams and ironstones, thickness about . .	1000
4. *Millstone Grit.*—Coarse grits, and sandstones, probably	200
5. *Yoredale Beds.*—Black shales, sometimes calcareous,—sandstones, and ironstones . . .	600
6. Carboniferous Limestone	2,000
	4,780

The Annahone District is much smaller. It is one mile long, and half a mile broad. It may, therefore, contain 320 acres. Sir R. Griffith states, however, that it is probable the district may extend a considerable distance farther to the south and east, and that coal may be wrought from beneath the New Red Sandstone. The coal-field is, moreover, covered to a considerable depth with drift deposits, which render the strata difficult of access.

The following is some account of the coal-seams at Coal Island in descending order: *—

	Yds.	Ft.	In.
Upper Coal (impure)	0	2	2
Strata	12	1	0
Annagher Coal (soft quality) . .	0	9	0
Strata	18	1	0
Bone Coal	0	3	0

* For analyses of coals and ironstones by Mr. Hardman, see Proc. Roy. Irish Acad., 2 sec., vol. ii.

	Yds.	Ft.	In.
Strata	13	0	0
Shining Seam	0	2	10
Strata	26	0	0
Brackaveel Coal (good quality) . .	0	5	0
Strata	28	0	0
Gortnaskea Coal {Cannel, 2 feet; Coal, 4 ,,} .	0	6	0
Strata	25	0	0
Baltiboy Coal (sulphureous) . .	0	3	0
Strata . . . . (about) .	65	0	0
Derry Coal (good quality) . .	0	4	6
Strata with 2 thin seams . . .	50	0	0
Yard Coal (good quality) . . .	1	0	0
Strata with two thin seams, and of uncertain thickness	(unknown)		
Creenagh Coal (with 14-inch cannel .	1	1	6
Strata, only partly proved and of uncertain thickness	(unknown)		
Drumglass Main Coal (variable) .	1	1	10
Strata (variable)	10	0	0
Lower Coal . . . 1ft. to	0	2	0

Millstone Grit.

Fossils.—The strata of the Lower Coal-measures are characterized by marine shells, such as *Orthoceras*, *Goniatites*, *Productus*, and *Lingula*, together with fish remains and plants. The beds above the *Creenagh Coal*, which may be taken as the upper limit of the Lower Coal-measures, are characterized by bivalves, as *Anthracosia*; but *Lingula squamosa* also occurs

above the "Yard" and "Baltiboy" seams, together with fish and plants, indicating estuarine conditions.

Antrim Coal-field.

The Antrim Coal-field, in point of geological interest, is unsurpassed by any other district in Ireland. It extends along the coast of Ballycastle Bay on the north, and Murlogh Bay on the south, separated from each other by the magnificent mural cliffs of Benmore or Fair Head, formed of columnar dolerite, which rise boldly from the sea to a height of 636 feet. The length of the coal-field is four miles, and the average breadth one mile and a half; coal has been wrought here from an ancient period (see p. 31).

The geological structure of this district has been investigated by several observers, including Dr. Berger,* Dr. Bryce,† and Sir R. Griffith, who, in 1829, drew up an able report, illustrated by drawings, for the Royal Dublin Society.‡

* "On the Geological Features of the Northern Counties of Ireland," Trans. Geol. Soc. Lond., 1st Series, vol. iii.

† "On the Geological Structure of the N.E. part of the County Antrim," *Ibid*, 2nd Series, vol. v.

‡ "Geol. and Mining Survey of the Coal-districts of Tyrone and Antrim." Dublin, 1829.

The most recent treatise is one by myself, in which the question of the geological age of the coal-bearing rocks is discussed; * a question to which I shall presently return.

Ballycastle Carboniferous-series.—This series may be arranged into the following divisions:—

(3) *Upper Beds.* About 240 feet in thickness.	Reddish and grey sandstones, sometimes coarse-grained and conglomeratic; shales with seams of coal, clay-band, and black-band ironstone; fossils, *Lingula squamiformis; Sagenaria (Knorria) imbricata, Sigillaria Lepidodendron, Stigmaria,* etc.
(2) *Middle Beds.* 55 feet.	Two beds of compact argillaceous limestone, 9 feet in thickness, fossiliferous, and imbedded in calcareous shales with numerous fossils. Fish; *Orthoceras Steinhauerii, Bellerophon Urii, Murchisonia angulata, Leda attenuata, Axinus deltoides, Rhynchonella pleurodon, Productus giganteus, Fenestella antiqua, Archæocidaris, Urii,* etc.
(1) *Lower Beds.* Thickness considerable but unknown.	Red and yellow sandstones, sometimes coarse, with beds of shale, and a seam of black-band ironstone; the base of the series being the conglomerate of Murloch Bay.

The entire thickness of the series is unknown, but probably exceeds 1,200 feet. The base is a quartzose conglomerate resting upon contorted

* "On the Geological Age of the Ballycastle Coal-field," etc., with Palæontological Notes by Mr. W. H. Baily, F.G.S., Journ. Geol. Soc. of Ireland, vol. ii., part 3, New Series, 1871.

mica-schist, with veins of quartz, as seen at the south end of Murlogh Bay.

Coal-series.—The coal-series of Ballycastle Bay, as ascertained at the mines now at work, is as follows :—*

	Ft.	In.
Top, or *First Coal* (splint seam) . . .	3	0
Sandstones and shales	30	0
Second Coal (Hawksnest seam) . . .	3	0
Strata, with black-band ironstone . .	240	0
Third Coal (main seam)	4	0
Strata, with black-band ironstone below the main coal, in some places . . .	60	0
Limestone (same as that in section above) .	8	0
Strata (shales and sandstones) . . .	240	0
Lower black-band ironstone (by boring) .	1	0
Total	589	0

In Murlogh Bay the section is different, but the beds of coal are considered to represent those in Ballycastle Bay. Here they are capped by columnar basalt, and a dyke of this rock intrudes itself amongst the strata, changing some of the coals into anthracite. Other basalt or dolerite dykes occur traversing the strata in Colliery and Ballycastle Bays ; and an enormous mass of this rock forms the limit in a northerly direction of

* Furnished to the Author by Mr. Gray, the mine manager, Ballycastle Bay.

mining operations. The strata are also traversed by several faults which displace the beds of coal.

The following is the section visible on the northern side of Murlogh Bay from the top of the cliff downwards, as given by Sir R. Griffith:—

Section in Murlogh Bay.

	Ft.	In.
Columnar Greenstone (about)	100	0
Brownish-red Sandstone	20	0
Bituminous Coal	1	0
Red Sandstone	80	0
Black Shale	6	0
White Mine Coal (highly bituminous) . .	2	6
Brownish-red Sandstone	40	0
Bituminous Coal	0	6
Red Sandstone	20	0
Black Shale	10	0
Bituminous Coal (Goodman's vein) . .	2	6
Black Shale	60	0
Uninflammable Carbonaceous Coal . .	2	6
Black Shale passing into flinty Shale . .	2	0
Second columnar Greenstone (basalt) . .	70	0
Black Shale	2	0
Non-flaming Coal, with thin beds of black Shale	8	6
Black Slate (base not visible) . . .	10	0
	437	6

Geological Age of the Antrim Coal-series.—In comparing the succession of strata at Ballycastle with those of the Ayrshire and Lanarkshire coal-fields, we cannot fail to be struck by the

several points of analogy they present. Amongst these are (1), the thick beds of red sandstones and conglomerates, which form the lower part of the series; (2), the occurrence of beds of black-band ironstone; (3), also of earthy limestone with Carboniferous Limestone fossils, and of a marine bivalve (*Lingula squamiformis*) over one of the coal-seams of the upper division. These, and other considerations, have led me to the conclusion, that the Antrim coal-series belongs to the same geological horizon as that of the Lower Coal and Ironstone Series of Scotland, which, as I have already shown, occupies the position of the "Yoredale Series" of the north of England. The base of this series is the Carboniferous Limestone, represented in the Ballycastle Coal-field by the thin band of limestone, eight feet thick, described above, while the underlying reddish sandstones, shales, etc., are referable to the "Calciferous Sandstone series" of the centre of Scotland. It will thus be evident that the Carboniferous Limestone has undergone a remarkable amount of deterioration as a limestone formation in its northerly extension in both countries.*

Black-band ironstone has been largely mined,

* Trans. Roy. Geol. Soc. Ireland, vol. ii. p. 260 (1871).

and calcined on the spot, from whence it can be exported to the furnaces on the opposite coast of Ayrshire.

RESOURCES OF THE IRISH COAL-FIELDS.

The estimates of the resources of the Irish coal-fields were entrusted to the Author, upon the decease of Professor Jukes, one of the Royal Commissioners; and the following are the results of the available quantities of coal, as published in the Report, and in arriving at which I had the assistance of my colleagues of the Geological Survey, Messrs. G. H. Kinahan and J. O'Kelly:—

	Tonnage unworked.	Net tonnage available for use.
1. Ballycastle, County Antrim	18,000,000	16,000,000
2. Tyrone (visible and concealed)	36,950,000	32,900,000
3. Queen's County, Kilkenny, and Carlow (Leinster)	86,202,000	77,580,000
4. Tipperary	29,500,000	25,000,000
5. Clare, Limerick, and Cork (Munster)	23,000,000	20,000,000
6. Connaught (Arigna district)	12,000,000	10,800,000
	205,652,000	182,280,000

The quantity of coal raised in Ireland is comparatively small, and much below what it ought to be, if all the coal-fields were properly deve-

loped. It will be seen from the above estimates that the districts of Tyrone and Antrim have considerable resources in mineral fuel, which are at the present time made use of to a very limited extent. I cannot, however, but look forward to an improvement in this respect, when the facts of the case become more generally known, through the publications of the Government Geological Survey now in progress.

In 1878, the quantity of coal returned as raised in Ireland was 121,975 tons from 50 collieries.*

* "Mineral Statistics." This is probably an under-estimate.

CHAPTER XXX.

ON THE QUANTITY OF COAL IN THE CONCEALED COAL-FIELDS OF CENTRAL ENGLAND.

Coal-resources of the British Isles.

BESIDES the coal stored in the known or visible coal-fields, it is unquestionable that very large quantities lie concealed beneath Permian, Triassic, and even Liassic strata beyond the margins of these coal-fields themselves. The extent and subterranean limits of these concealed reservoirs have been the subjects of investigation on the part of physical geologists for some years past; but it is only very recently that our knowledge of the physical geology of the British Isles has been sufficiently advanced to enable us to arrive at anything like definite results on this question.

The solution of this interesting problem depends on the proper determination of three distinct branches of investigation. The first of these is the restoration of the original limits, or

margins, of the Carboniferous rocks; secondly, the extent and direction of the areas of upheaval and depression over which the subsequent terrestrial movements have taken place; and thirdly, the amount of denudation which has accompanied or followed these terrestrial movements.

As the determination with any degree of precision of these severally simple problems, merging into the complex one, depended on a multitude of minute observations made over the whole area, and properly laid down on maps, the question itself was not ripe for solution until the country had been geologically mapped by the Government Surveyors; so that, had the attempt at solution been made at an earlier period than the present, it must have failed, simply from the want of the necessary details. It was, therefore, fortunate that the appointment of a Royal Commission (part of whose duty was to report upon this question) was reserved for the present time, when the Government Surveyors had extended their investigations over nearly the whole of the districts of England occupied both by the coal-fields and the more recent formations, and were in a position to supply all the necessary details for the proper consideration of this complex

problem, in addition to the voluntary assistance readily tendered by many private observers.

One of the earliest attempts to define the limits of the concealed coal-fields was that made by the late distinguished Director-General of the Geological Surveys, Sir Roderick Murchison, who, upon the occasion of the meeting of the British Association at Nottingham, in 1866, read an essay on the subject* before the Geological Section. In this paper the writer combats the view of the existence of workable coal, either under the Cretaceous rocks of the south of England, or of the Triassic rocks east of the Malvern Hills; while he points out that these hills themselves on the west, and the Cambrian Rocks of Charnwood Forest on the north-east, then full in view from Nottingham Castle, formed the "salient promontories" of the southern coast line, or margin, of the original coal-fields.

Having for several years, while engaged on the survey of the midland and western counties of England, kept the question steadily before me, as one of the very highest economic importance, I had the gratification of laying my views before

* "On the Parts of England and Wales in which Coal may or may not be looked for."—Trans. Brit. Assoc., 1866.

the Royal Coal-Commission, in which I entered into the whole question, as far as it related to the midland and northern counties; and at the request of the Committee, to which this branch of inquiry was delegated, I prepared a small map, showing what appeared to be the probable subterranean limits of the coal-formation.* These views were shortly afterwards repeated, or expanded, in a memoir, which I drew up for the Geological Survey, "On the Triassic and Permian Rocks of the Central Counties of England" in 1869.†

In his memoir on the "Geology of the South Staffordshire Coal-field," the late Professor Jukes had thrown considerable light on the question of the limits of the Coal-measures of the central counties towards the south, and had also recognised in the rocks of Charnwood Forest the original margin of the old Carboniferous area—a question on the determination of which the whole internal structure of the central counties hinges.‡

* The evidence and map are to be published with the Report of the Commission, vol. ii.

† "Distribution of the Coal-measures beneath the Triassic and Permian Rocks," chap. xi., p. 109.

‡ "Geol. South Staffordshire Coal-fields." Preface to 2nd edit., 1859.

POSSIBLE OCCURRENCE OF COAL UNDER THE SOUTH OF ENGLAND.

With reference to the south of England, Mr. Godwin-Austen, in 1855, read an able paper before the Geological Society of London, in which he discusses the question of the probable extension of the Coal-formation beneath the Cretaceous rocks lying between the coast opposite Calais and the Somersetshire coal-field; and endeavours to show that the Coal-measures which tail out under the Chalk near Thérouanne probably set in again near Calais, thence are prolonged in the line of the Thames Valley parallel with the North Downs, and continue under the Valley of the Kennet into the Bath and Bristol coal-area. These views were repeated and amplified by Mr. Godwin-Austen in his evidence before the Royal Commission.

With the view of putting the question of the existence of the Carboniferous rocks under the tract lying to the south of the North Downs to the test of experiment, a boring was undertaken by private enterprise in 1873, with a Government subsidy, in a position (as nearly as circumstances would permit) in the lowest beds of the Wealden Series in Sussex. Unfortu-

nately for the object in view, the Secondary rocks proved of unexpected thickness, and the boring was abandoned at a depth of 1820 feet, in beds of coarse Oolite considered to belong to the Coralline Oolite formation, the Palæozoic rocks not having been reached.* From the statement of Mr. Topley it would seem that the Kimmeridge Clay was entered at a depth of 255 feet, and extended down to 1769 feet, giving an unprecedented thickness of 1514 feet for this formation. Whatever portion of the Palæozoic series may underlie this district, it is clear that the depth is much greater than was previously supposed.

Artesian Well, Tottenham Court Road, London.—Of still greater interest, as bearing on the internal structure of the strata under the London Basin, is the boring in search of water recently carried out by Messrs. Meux & Co. in Tottenham Court Road. Several accounts have been given of this undertaking, but the most recent is that by Professor Prestwich, in which he discusses the relations of the strata proved in the boring to those of the adjoining districts

* See Third Report, by Mr. H. Willett and Mr. W. Topley, of the Sub-Wealden Exploration Committee. Rep. Brit. Assoc. 1875, p. 346-7.

of France and Belgium.* The general Section was proved to be as follows :—

Section at Messrs. Meux & Co.'s Boring, London.

Gravel and Tertiary Strata	156½	ft.
Middle and Lower Chalk	655	,,
Upper Greensand	28	,,
Gault.	160	,,
Lower Greensand	64	,,
Upper Devonian Beds	80	,,
Total.	1144	,,

The Upper Devonian beds, the fossils from which were determined by Mr. R. Etheridge, were found to consist of reddish, purple, and light-green shales, hard and finely micaceous, having an angle of dip of 35°, whereas the overlying Cretaceous strata are nearly horizontal.

Much uncertainty might have existed regarding the geological age of these beds had it not been for the occurrence of fossils at intervals in the cores, among which Mr. Etheridge recognised the following:—*Spirifera disjuncta*, *Rhynchonella cuboides*, *Edmondia*, *Orthis*, *Chonetes*, and Prof. Prestwich adds *Rhynchonella Boloniensis*, characteristic of the Upper Devonian beds of Belgium. Although the angle of dip was easily determinable by measurement with the walls of the cores,

* Quart. Journ. Geol. Soc., vol. xxxiv., p. 902.

the direction of the dip remains uncertain,—an unfortunate circumstance, as we do not know whether it was towards the north or towards the south.

Crossness Boring.—Another boring also throwing light on the nature of the Palæozoic rocks under the Thames Valley is that recently made in search of water at Crossness by the Metropolitan Board of Works on the south bank of the Thames near Blackwall, the abbreviated section of which is as follows:—

	Thickness.	
1. Alluvial and Quaternary beds . .	39	feet.
2. Tertiary beds	97	,,
3. Middle and Lower Chalk . . .	638	,,
4. Upper Greensand	65	,,
5. Gault	176	,,
6. Old Red Sandstone or Devonian . .	60	,,
Total .	1,075	,,

The strata indicated as "Old Red Sandstone or Devonian" are somewhat similar to those in the boring at Tottenham Court Road, and are considered by Prof. Prestwich to be identical therewith.*

To the above must be added the boring and well at Kentish Town, in which at a depth of 1114 feet strata of hard micaceous red and variegated

* Prestwich, *supra cit.*, p. 913.

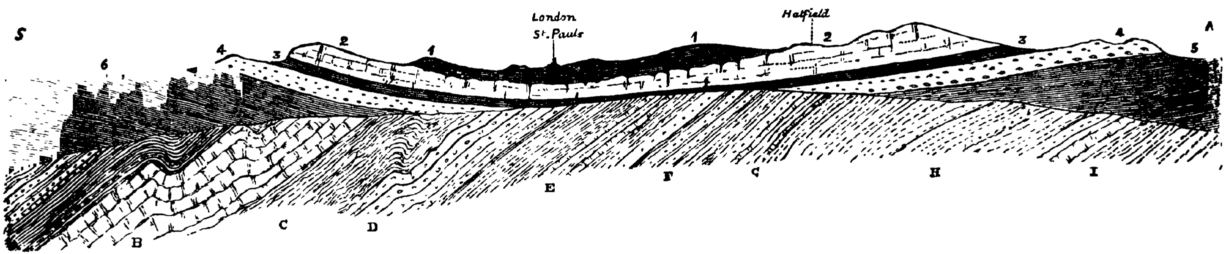
fine-grained sandstones and shales were encountered below the Gault, and penetrated for a depth of 188 feet. The resemblance of these beds to those at the boring in Tottenham Court Road has removed any doubt which might previously have existed that they belong to the Devonian series.

Whatever, therefore, may be the nature of the Palæozoic strata at some distance to the south of the Thames Valley near London, no doubt can remain that the Coal-formation is absent under London itself, and as the strike of the Palæozoic beds may be assumed to be about W.N.W. and E.S.E., we must look to the tracts lying south of the Thames Valley as the *possible* areas of concealed Coal-fields.

As bearing upon this view, the discovery of true Coal-measures at Burford, in Oxfordshire,* at 1184 feet from the surface, is exceedingly interesting, and may help to indicate the position of one of the Palæozoic troughs or basins in which coal may be expected to lie. Thus if we draw a line along the centre of the South Wales Coalfield, and thence prolong it through that of the Forest of Dean, it will be found to pass by Burford, around which a small coal-basin like that of the

* In a deep boring through the Triassic strata carried out by Mr. Fox, 1877.

Fig. 21.—SECTION NORTH AND SOUTH THROUGH THE LONDON BASIN—SHOWING PROBABLE POSITION OF CONCEALED PALÆOZOIC ROCKS.



EXPLANATION.

A. Middle Carboniferous Beds.
B. Carboniferous Limestone.
C. Carboniferous Slate, etc.
D. Old Red Sandstone (Upper Devonian).
E. Middle Devonian Beds.
F. Lower Devonian Beds.
G. and H. Upper Silurian „
I. Lower Silurian „

1. Tertiary Beds.
2. Chalk and Upper Greensand
3. Gault Clay.
4. Lower Greensand.
5. Wealden Series.
6. Oolitic or Jurassic Beds.

Length of Section about sixty-five miles.

Forest of Dean may be supposed to extend. The recent and important discovery of Upper Silurian rocks under the Gault formation at Ware in Hertfordshire will induce caution in theorizing regarding the presence of possible coal-basins under the Cretaceous beds north of London.* These rocks were proved at a depth of 800 feet, in a boring for water which passed through the Chalk and Gault formations; and the result goes far to corroborate the view I had formed, several years previously, of the nature of the rocks underlying the Mesozoic formations over the Eastern counties of England.† With Upper Silurian (Wenlock) beds under Hertfordshire, and Middle Devonians under the centre of London, we are in a position to form a tolerably accurate conclusion regarding the succession of the beds, their dip and strike, and the direction in which we must look for coal in the neighbourhood of London. It is clear that the general dip of the palæozoic strata is towards the South, and that, as Mr. Godwin-Austen has pointed out, the possible

* The first announcement of this discovery was made by Mr. R. Etheridge, F.R.S., in a letter to *The Times*, 19th May, 1879.

† This is illustrated by the "Ideal Transverse Section of England," Fig. 24, which was published in 1861 in the 2nd edition of this work; and in which the "Silurian and Cambrian" rocks are shown as underlying the Cretaceous in the Eastern Counties.

coal-fields are to be looked for along the margin of the North Downs and the borders of the Wealden area. This general succession of the beds I have endeavoured to indicate, as far as our knowledge permits, in the accompanying section (Fig. 21), taken north and south through London and Hertford. A fresh trial for coal under the Weald is still much to be desired.

It would appear, therefore, that London is built upon the back of a ridge of upper palæozoic rocks, which probably sloped downwards both to the north and to the south. The centre of this ridge immediately under London is formed of Devonian beds; and we may suppose that in a southerly direction Carboniferous rocks set in. This ridge, formed at the close of the Carboniferous period, remained as a land-surface during the Triassic, Oolitic, and Lower Cretaceous periods, and was only completely submerged and covered up when the Upper Cretaceous beds began to be formed. In this arrangement of the strata, the basin of the Thames may be considered as a prolongation of the geological features of the adjoining districts of France and Belgium.*

* Somewhat similar sections are given in Mr. Whitaker's "Geology of the London Basin," Mem. Geol. Survey, p. 349, and in Prof. Prestwich's Paper above quoted.

CHAPTER XXXI.

VISIBLE COAL FIELDS.

HAVING discussed the question of the extension of the Coal-measures under the newer formations in districts where this is purely inferential, I proceed to offer statistical estimates of the quantity of coal still remaining both in the visible and known concealed coal-fields. I will first take the estimate of the Commissioners in 1870, and, in a separate column, these estimates corrected down to the year 1880.*

* I regret that the Mineral Statistics for 1879 collected and arranged by Mr. Hunt and his assistants of the Mining Record Office in London, were not issued in sufficient time to allow of my making use of them in these pages. The results as regards the out-put of coal in special coal-fields are probably not very different from those of the year 1878; and, of course, the out-put of a single year only very slightly affects the general result.

1.—VISIBLE COAL-FIELDS.

Commissioner.	No.	Name of Coal-field.	Amount in tons to a depth of 4,000 feet, and after necessary deductions.	Amount corrected to the year 1880.
Messrs. Vivian and Clark ...	1	South Wales	32,456.208.913	32,166 millions of tons.
Mr. Dickinson	2	Forest of Dean	265.000.000	260 " "
Mr. Prestwich	3	Bristol and Somerset ...	4,218,970.000	4.210 " "
Mr. Woodhouse	4	Warwickshire	458,652,714	445 " "
Mr. Hartley	5	South Staffordshire	1,906,119,768	900 " "
Do.	6	Coalbrook Dale		12 " "
Do.	7	Forest of Wyre		10 " "
Mr. Woodhouse	8	Leicestershire	836,799.734	826 " "
Mr. Dickinson	9	North Wales	2,005.000.000	1,985 " "
Do.	10	Anglesea	5.000,000	5 " "
Mr. Elliot	11	North Staffordshire	3.825.488.105	3.680 " "
Mr. Dickinson	12	Lancashire and Cheshire ...	5,546.000.000 200.000.000	5.165 " "
Mr. Woodhouse	13	Midland	12,220.000.000	12,000 " "
Do.	14	Black Burton	70,964,011	
Mr. Forster ... ... Mr. Elliot	15	Northumberland and Durham	10,036,660,236	7,152 " "
Mr. Forster	16	Cumberland	405.203,792	400 " "
		SCOTLAND.		
Mr. Geddes	17	Edinburgh	2.153.703.360	
Do.	18	Lanarkshire	2.044.090,216	
Do.	19	Fifeshire	1,098.402,895	
		Carried forward	79,752,283.744	69.216 " "

1.—VISIBLE COAL-FIELDS (*continued*).

Commissioner.	No.	Name of Coal-field.	Amount in tons to a depth of 4,000 feet, and after necessary deductions.	Amount corrected to the year 1880.
		Brought forward	79.752.283.744	69,216
Mr. Geddes	20	Ayrshire	1,785,397.089	
Do.	21	East Lothian	86,849,880	
Do.	22	Firth of Forth	1,800,000,000	
Do.	23	Dumfriesshire	358.173,995	
Do.	24	West Lothian	127,621 800	
Do.	25	Perthshire	109,895.040	
Do.	26	Stirlingshire	106,475,436	9,643 millions of tons.
Do.	27	Clackmannanshire	87,563,494	
Do.	28	Dumbartonshire	48 618 320	
Do.	29	Renfrewshire	25,881,285	
Do.	30	Argyleshire	7,223,120	
Do.	31	Sutherlandshire	3.500,000	
Do.	32	Roxburghshire	70,000	
		IRELAND.		
Professor Jukes, commissioner (*deceased*), and Professor Hull.	33	Ballycastle (Antrim Co.) ...	16,000,000	
Do.	34	Tyrone	6.300,000	
Do.	35	Leinster (Queen's Co.) ...	77,580,000	150 ,, ,,
Do.	36	Tipperary	25,000,000	
Do.	37	Munster (Clare, etc.) ...	20,000,000	
Do.	38	Connaught	10.800,000	
			84.455,213,203	79.009 ,, ,,

2. Concealed Coal-fields.

Summary of probable Amount of Coal under Permian and other overlying Formations at Depths of less than 4,000 feet, 40 per cent. deducted for loss and other contingencies; by Professor Ramsay, F.R.S., Commissioner.

Districts.	Under.	Sq. miles.	Tons.
Warwickshire	Permian	73	2.165,000,000
Warwickshire, south of Kingsbury	New Red	5	150,000,000
Warwickshire, north of Atherstone	New Red	6	179,000.000
Leicestershire, Moira district ...	Permian	15	1,000,000,000
Leicestershire, Coleorton district	New Red	25 to 28	790,000,000
District between the Warwickshire and South Staffordshire Coal-fields	Permian and New Red	116	3,400,000,000
District between South Staffordshire and Shropshire Coal-fields	"	195	5,800,000,000
Between the South Staffordshire and Coalbrook Dale Coal-fields to the Cheadle and North Staffordshire Coal-fields	"	200	4,580.000,000
East of the Denbighshire Coal-field	"	50	2,489,000,000
West and S.W. border of the North Staffordshire Coal-field	"	50	1,500,000,000
Cheshire, west of the Kerridge ...	Permian and New Red	9	62,000,000
Cheshire, between Woodford Fault and Denton	"	36	1,790,000,000
Lancashire, east and west of Manchester	"	30	350,000,000
Lancashire, west of Eccles and Stretford to Prescott, Runcorn, and Hale-on-the-Mersey ...	"	130	3,883,000,000
The Wirrell, the Mersey, and country to the north	New Red	216	3,000,000,000
Yorkshire, Derbyshire, and Nottinghamshire	Permian and New Red	900	23,082,000,000
Vale of Eden	Permian	40	1,593.000.000
Ingleton and Burton	"	3	33.000,000
Severn Valley	New Red Marl	45	400,000,000
Ireland, Tyrone (Professor Hull)	New Red Marl and Sandstone	2,400 acres	27,000,000
		Total ...	56.273,000,000

General Summary,

Showing (in round numbers) the presumable quantity of coal in reserve in the year 1880, at depths not exceeding 4,000 feet.

	tons.
Quantity of available coal in visible coal-fields	79,752,000,000
In concealed Coal-measures . .	56,273,000,000
Total	136,025,000,000

It therefore appears that there exists within the limit of depth above stated, and after making due allowance for the loss and waste inseparable from mining, a supply of coal of over ONE HUNDRED AND THIRTY-SIX THOUSAND MILLIONS OF TONS,—a supply which, if drawn upon at the rate of one hundred and thirty millions of tons, the quantity for 1878, would be sufficient to last for more than a thousand years. But it is impossible to regard the subject from this point of view: first, because the produce of the coal-fields is a variable and increasing quantity; and secondly, because the coal can never be exhausted otherwise than by a gradual and slow process.

To this question we shall return: meanwhile,

the result of the calculations of the Commissioners must be satisfactory to the public at large, as demonstrating that for a long period to come British commerce is not likely to languish, or British household fires to smoulder, for want of that prime necessary of British life—COAL.

PART III.

CHAPTER I.

COAL-FIELDS OF EUROPE.

Before proceeding to the description of the separate Coal-fields of Europe, it may be desirable to place before the reader, in a tabular form, the representative groups of the British Isles and of Europe. This Table will show at a glance what members of the great Carboniferous system are present in each country; and it will be observed that, owing to denudation, the uppermost division is generally absent on the continent. As regards the succession of strata, there is evidence of a remarkable resemblance over large areas; a resemblance which is also conspicuous in the case of the organic remains which characterise the strata. The ternary division shown in the table is founded both on physical and palæontological evidence.

TABLE OF CONTINENTAL EQUIVALENTS OF BRITISH CARBONIFEROUS DIVISIONS.*

Divisions.	Stages.	British Equivalents.	France.	Belgium.†	Rhenish Provinces, etc.	Silesia, etc.
UPPER CARBONIFEROUS (essentially estuarine and lacustrine).	G.	Upper Coal-measures.	....	. ...	... .	Coal-measures. "Étage hangende" (Lottner)?
	F.	Middle Coal-measures.	Alais, St. Etienne.	Douai and Hainaut (Bassin de Namur).	Saarbrück, Dortmund, and Westphalian Coal-fields.	Coal-measures. "Étage mittlere" (Lottner).
MIDDLE CARBONIFEROUS (essentially marine).	E.	Gannister beds, etc.	Schistes de Lens, Auchy-au-Bois.	Schistes alunifères de Chokier, de camp de Casteau près Mons.	Dark shales with marine shells (Westphalia) Lower stage (Lottner).	Black shales (schwartze Schieferthon) with marine shells. "Étage liegende" (Lottner).
	D.	Millstone-Grit series.	Not recognized.	Schistes des Ampélites?	Flötzleerer Sandstein of Rhenish Prussia.	Lower Sandstones of the Hartz, etc. (Murchison).
	C.	"Yoredale series" of the Geol. Survey.	. ...	Calcaire de Visé.	Not recognized.	Not recognized.
LOWER CARBONIFEROUS (essentially marine, sometimes lacustrine at base.)	B.	Carboniferous Limestone.	Calcaire de Lille, Sablé, etc.	Calcaire de Dinant, Tournai, Namur, etc.	Dark limestones and schists with *Posidonomya Becheri*.	Beds of Limestone, (often absent).
	A.	Lower shales, slates. calciferous sandstones, and conglomerates.	....	Schistes de Tournai.	"Kieselschiefer."	Replaced by older rocks.

* This table is extracted from my paper on the Classification of the Carboniferous Series, Quart. Journ. Geol. Soc., Nov. 1877, and has been accepted by several continental geologists of eminence. A slight inaccuracy has been corrected at the instance of my friend Dr. C. Barrois of Lille.

† To stage E in the Belgian series the second "niveau fossilifère" of MM. Briart and Cornet is referable, with *Productus carbonarius*, *Chonetes Laguessiana*, a *Cardinia*, and *Avicula*; to which Prof. Dewalque has added *Orthis crenistria*, *Posidonomya v. tusta* (?), *Goniatites*, *Pecten*, and *Terebratula* (Bull. de l'Acad. Roy. de Belgique, 2e sér. t. 33, no. 1, 1872).

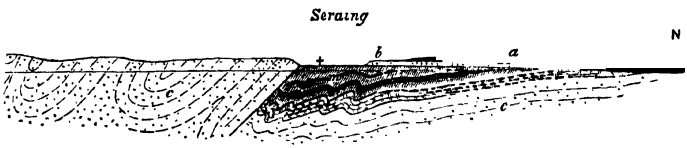
France and Belgium.—The Coal-formation of these countries extends in a long and narrow trough from Aix-la-Chapelle westward, by Liége, Namur, Mons, Valenciennes, Douai, and Arras, near which place it is concealed beneath nearly horizontal beds of Cretaceous and Tertiary rocks. West of this town, however, the coal has been proved to a distance of 80 miles, valuable beds having been found at Therouanne; and again they reach the surface a few miles north-east of Boulogne. Between the coal-field of Valenciennes and Boulogne, there is a large upcast fault bringing up the Devonian rocks, so that the Boulogne coal-district is a distinct basin.* Here the dip is north, and the Carboniferous Limestone rises from below the Coal-measures. Before entering the sea at Calais, the Carboniferous strata are concealed by Lower Oolite, and nowhere reappear across the south of England till we reach Somersetshire.

The Franco-Belgian coal-trough is not everywhere continuous, being dissevered into elongated basins east of Mons, by the elevation of the Lower Carboniferous rocks. These latter themselves, as in the north of England, some-

* As I have been informed by M. Louis Aguillon, mining engineer.

times contain coal which has been mistaken for that of the true Coal-formation; and at Liége and Mons the strata are repeatedly crumpled, and thrown into a vertically zig-zag position, so that the same shaft passes several times through the same seam of coal. We have analogous cases along the northern flanks of the Mendip

Fig. 22.—SECTION ACROSS THE COAL-FIELD OF LIÉGE. 18 Miles.*



a, Tertiary Beds. *b*, Cretaceous. *c*, Devonian. N, Carboniferous.

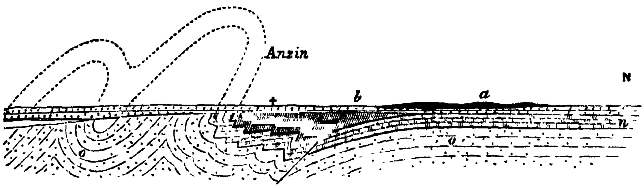
Hills in Somersetshire, but not so generally known. The whole length of the trough, measured from Aix-la-Chapelle to Calais, and considered as continuous, is about 210 miles; but the breadth is variable, and never great.

The united extent of these coal-fields is probably nearly 1,200 square miles; but there is a considerable tract between Valenciennes and Calais, overspread by Chalk and Tertiary formations, under which the Coal-measures have not yet been proved, and where they lie at consider-

* This and Fig. 23 are taken from a drawing by Mr. Prestwich, F.R.S., in Report of the Royal Coal-Commission.

able depths.* The general arrangement of the strata in this part of their course is shown in the following section (Fig. 23).

Fig. 23.—SECTION ACROSS THE COAL-FIELD AT VALENCIENNES. 13 Miles



a, Tertiary Beds. *b*, Cretaceous. N and M, Lower and Upper Carboniferous.

I shall now state the names of the towns and villages situated along this trough, from west to east, taking as a guide the map of M. A. Dumont.† Commencing at Lillers in Artois, it ranges by Bethune, Douai, Valenciennes, Condé, Mons, Namur, Huy, Liége, Aix-la-Chapelle—where the strata are folded into several distinct troughs ; and about ten miles east of this town the Coal-measures become entirely concealed beneath the alluvial plain of the Rhine. Their course beneath this plain would appear to be north-east, by Juliers and Kaiserwerth, to the

* MM. Dufrénoy et Elie de Beaumont, Carte Geologique de la France.

† Carte Geologique de la Belgique. See, also, the elaborate maps and sections in the "Atlas zur Geologie der Steinkohlen Deutschlands," etc., von Dr. Geinitz, Munich, 1865.

Valley of the Ruhr, at the margin of the coal-field of Westphalia.

The depth of the Liége coal-basin at Mont St. Giles, according to Herr Von Oeynhausen, reaches to 3,809 feet below the surface, and the coal-basin of Mons is fully 1,865 feet deeper still. But this is small in comparison with the depth attained by the strata in the Saarbrück coal-field.

There are also several small coal-fields in France surrounding the central granitic plateau, of which the following are the principal :—

That of St. Etienne, about 15 miles long by 6 broad, yielding about 6 millions of tons of coal annually ; the basin of the Saone et Loire ; and the basin of Alais, in the department of Gard and Ardèche. There is also the coal-district of Ronchamp in the department of Haute Saône ; and the anthracite district in the department of Isère, or the Basin des Drac.*

Rhenish Provinces of Prussia : the Saarbrück Coal-field.—This is the largest and most important coal-field in western Europe, having an area of about 900 square miles. Along its western borders it is traversed by the river Saar,

* "Die Steinkohlen Deutschlands," etc., 1 band, cap. xii., 351.

between the towns of Saarlouis and Saarbrücken, and extends in an easterly direction to Wellesweiller, where the beds pass below the Bunter Sandstone, which stretches along the southern borders of the coal-field, and along the valley of the Saar forms also the western boundary. The coal-seams, however, have been worked below this newer formation at intervals all along the margin.*

Towards the north, the coal-formation rests upon the Devonian schists of the Hundsrück (the "Koblenzer oder Spirifer-Schichten"), the general dip being southward, in which direction the Coal-measures pass below the Permian beds and New Red Sandstone of the Vosges. There are extensive intrusions of igneous rocks, especially along the northern outcrop, which detract from the mineral value of the district affected by them.

According to the observations of Herr von Dechen,† the thickness and depth of the Coal-measures in the Saarbrück basin is very great.

* See the admirable chart and description of this coal-field by H. von. Rönne, Royal Inspector of Mines, in "Die Steinkohlen Deutschlands," vols. i. and ii.

† Geognostische Umrisse der Rheinlander zwischen Basel und Mainz, etc., v. H. v. Oeynhausen, H. v. Dechen, und H. v. La Roche (1825).

From several measurements it was found that the lowest coal-strata known in the district of Duttweiler, near Bettingen, descend to a depth of 20,682 English feet, or 3·6 geographical miles below the level of the sea. This is a depth below the sea equal to the height of Chimborazo above it; and at this depth the temperature may be inferred to range as high as 467° Fahr.

This coal-field is remarkable for having yielded the remains of several species of reptiles, discovered by Mr. Leonard Horner, and named by Professor Goldfuss *Archegosaurus*, having characters intermediate between the Batrachians and Saurians.* There are also fish of the genera *Amblypterus*, *Palæoniscus*, *Acanthodes*; Crustacea, as *Uronectes*, *Estheria tenella*, *Leaia Bantschiana*; and Molluscs, *Unio carbonarius* (Bronn), *U. Kirnensis* (Ldwg.) The plant remains are abundant, and amongst others include the more common Carboniferous genera, such as *Lepidodendron*, *Sigillaria*, with *Stigmaria ficoides*, *Ulodendron*, etc.†

The Coal-fields of the Kingdom of Saxony.—The coal-formation of Saxony is distributed into

* Geinitz, "Steinkohlen," vol. i., 150.

† A complete list is given by Dr. Geinitz, in the work quoted. *Supra cit.* p. 369.

a series of beds which, collectively, may be regarded as a representative series of the formation in Germany. Dr. Geinitz distinguishes in it five successive zones of vegetation, which have appeared at intervals during a long lapse of time.

The Coal-basin of Zwickau-Chemnitz.—This coal-field lies to the north of the Erz Gebirge, the range of mountains which forms the southern border of Saxony, and extends from the village of Marienthal, west of Zwickau, on the south-west to Liegmar, near Chemnitz, on the north-east, a distance of 4 geographical miles. Along the south the Carboniferous beds repose on Silurian and Devonian rocks.* Towards the north they are overlaid unconformably by a massive conglomerate with pebbles of quartz, schist, and granite; and this by other beds of sandstone, shale, and porphyry, referable to the Permian series (Rothliegende).

The coal-field contains about 12 seams of workable coal, one of which, the "Russkohlflötz," is 12 ells in thickness.†

Plant-remains.—The lowest beds are characterised by *Sigillaria alternans*, *S. oculata*, *S.*

* Geognostische Karte von Sachsen, Section xv.

† Die Steinkohlen Deutschlands, vol. i., 56.

Cortei, etc., *Sagenaria dichotoma*, *Neuropteris auriculata*, *Asterophyllites foliosus*, etc. Above this is the "Annularian Zone," with *A. longifolia*, *Sphenophyllum emarginatum*; next the "Zone der Farren," (or Zone of Ferns), with *Sphenopteris irregularis*, *Sph. Macilenta*, *Odontopteris Reichiana*, *Neuropteris auriculata*, etc., *Lycopodites Gutbieri*, *Nœggerathia palmæformis*.

Coal-basin of the Plauenscher Grund, near Dresden.—This coal-field is traversed by the Weisseritz, a short distance above Dresden, and has its longest diameter of 1½ geographical mile, in a N.W. and S.E. direction, at right angles to the course of that stream.

The Coal-measures rest upon an irregular basis of syenite, porphyry, and (at the "Augustus" colliery) of clay slate, against a shelving bank of which the coal-seams terminate in a S.W. direction. The formation is overlaid by the conglomerate base of the Rothliegende, which is succeeded by higher divisions of the Permian series.

The coal is condensed almost into one principal and very thick seam, which is much broken by faults, and subjected to irregularities of dip and horizontal extension. The plant remains

are similar to those already described for the Zwickau-basin.*

Saxony contains, besides the above, culm-measures at Ebersdorf; anthracite in the Upper Erzgebirge, and a small coal-field at Flöha and Gückelsberg.

Westphalia.—This coal-field extends from the right bank of the Rhine at Duisburg and Ruhrort, at its junction with the Ruhr, and extends along both banks of that river as far as Herdecke, and Wetter, in an easterly direction, a distance of about forty-six miles. The strata belong to the Carboniferous system, reposing on beds of Millstone Grit (Flötzleerer sandstein), which in turn overlie Carboniferous Limestone and Culm-measures; the limestone, however, thins away eastward.† Towards the north, the Coal-measures pass below Cretaceous strata (Kreide-mergel), which rest unconformably on the convoluted edges of the Carboniferous rocks.

The Coal-measures have been bent into a great number of remarkably regular folds, not very sharp, and with their axes ranging in an

* Map and section of this coal-field, by Dr. Geinitz.—"Die Steink. Deutsch.," plates iii. and iv.

† The Culm-shales contain *Posidonia Becheri.*—"Siluria," 3rd edit., p. 427.

average direction of E. 25° N. The consequence of this structure is, that the coal-seams are arranged in a series of narrow troughs, from thirteen to fifteen in number, when counted across the centre of the field. These flexures, on the whole, dip very gradually towards the E.N.E., and rise in the direction of the Rhine Valley, where they terminate; so that at Ruhrort, the coal-field is contracted to a narrow band. That it crosses under the river, and underlies the town of Meurs, there can be little doubt. The flexures I have described are clearly referable to the same system as those which have bent and folded the coal-seams of Belgium and the North of France.*

Coal-field of Ibbenbüren, N.W. Germany, examined and described by Herren Heine and Dortmond,† belongs to the Carboniferous formation with *Calamites*, *Sigillaria*, *Sphenopteris*, *Neuropteris*, etc. The Coal-measures, with five workable coal-seams, are overlaid by Zechstein (Permian Limestone) and Triassic strata, along their southern borders.

* For map, sections, and description of this coal-field, the reader is referred to "Die Steinkohlen Deutschlands," etc., vols. i. and ii.

† Zeitschrift der Deutschen Geolog. Ges. Berlin, 1861.

Coal-field of Piesberg, near Osnabrück, in Hanover.—This coal-field, though now separated from that of Ibbenbüren, seems once to have been continuous with it; some of the seams of coal having been identified by Herr v. Velsen. The strata consist largely of sandstone and conglomerate with nine coal-seams, amongst which Prof. Römer has identified a large number of plants of the Carboniferous species, including the root-stalk *Stigmaria ficoides*, *Sigillaria striata*, *Lepidodendron dichotomum*, *L. elegans*, *Alethopteris pteroides*, *Sphenopteris gracilis*, *S. nervosa*, *Calamites Suckovii*, etc.*

Bohemia.—According to the accounts of M. Michel Chevalier, nature has left to Bohemia a rich dowry of mineral fuel. Besides the older coal-bearing strata, there are very extensive areas underlaid by lignite of excellent quality, now worked in the north-western districts.

M. Chevalier considers that the coal-formation belongs to two different ages, that of Eastern Bohemia to the Lower Permian or Rothe-todte-liegende; that of Western to the true Carboniferous system. The former extends in a band along the base of the Chaîne des Géants (Riesen

* Die Steinkohlen Deutsch., Band i., 201.

Gebirge). This band is probably connected with the coal-formation of Silesia.

The western formation is distributed into three basins. 1st, that of Rakonitz; 2nd, that of Radnitz; 3rd, that of Pilsen. Of these, the basin of Rakonitz is the most extensive.

The flora of Rakonitz and Radnitz, described by M. Stur and Count C. Sternberg respectively, consist of about 21 genera of Carboniferous plants.

The Weald Coal-formation of North-west Germany.—In Hanover and N.W. Germany there occurs a great series of beds attaining a thickness of about 2,000 feet, which, according to the researches of Herr Credner, are referable to five stages,—

1. *Wälderthon* (with *Melania*), representing the Weald clay of England.
2. *Wäldersandstein* (or Deister sandstein), representing the Hastings sand of England.

3. *Serpulit*, limestones and shales	.	Representing the Purbeck beds of England.
4. *Mündermergel*, marl and dolomite	.	
5. *Plattenkalk*, with *Corbula inflexa*	.	

These beds are underlaid by the Jurassic formation (Weisser und Brauner Jura), and dip beneath Neocomian and Chalk strata, and are traversed by the rivers Vechte, Ems, Haase, and Weser, near Minden, and from thence extend in

an interrupted band nearly to the bank of the Leine, south of Hanover.

The greater number of coal-seams occur in the upper member of the group (Weald Clay), the section at Deister showing about fifteen seams of coal, of which the greater number, however, are impure.

Silesia.—This coal-field is very extensive. It stretches from the eastern base of the Riesengebirge, at Bober and Schatzlar, in a semicircle by Landschut, Gottesberg, Waldenberg, and Tannhausen, to Eckersdorf, near the banks of the river Neisse. The Coal-measures have, in general, a base of Carboniferous Limestone, except towards the eastern portion, where they repose directly upon gneissose strata. They in turn are overlaid by Lower Permian (Rothliegende) and Cretaceous formations, and are often invaded by masses of porphyry and other igneous rocks.*

The coal-formation contains several valuable seams of coal, worked in several localities, as at the colleries of Louise, Gustav, Emili, Morgen und Abendstern, Finstern, Frans-Joseph, and Segen-Gottes, Friedrich Wilhelm, and many others.

* See map and description of this coal-field in vols. i. and ii. of Die Steink. Deutsch.; also Murchison's "Siluria," p. 391-2.

On the organic remains of this coal-field the writings of Dr. H. R. Göppert have thrown much light. This observer arranges the formation into zones characterised by special plants, such as *Stigmaria*, *Sagenaria*, and *Lycopodacea;* which Dr. Geinitz endeavours to identify with certain stages in the Coal-measures of Saxony. The usual Carboniferous genera of *Sigillaria*, *Stigmaria* (root), *Næggerathia*, etc., are here well represented.

Bohemia also contains extensive areas underlaid by lignite of excellent quality.

Prussian and Austrian Silesia.—This coal-field lies on the borders of Poland, being traversed by the river Weichsel. The strata are referable to the Carboniferous system, and coal is extensively worked between Beuthen and Kostow.

Moravia.—The coal-field of Eastern Moravia lies along the banks of the Oder, and its tributary the Ostrawitza, for some distance upwards from their confluence; and mining operations are extensively carried on at Koblan, Hruschau, Petrzkowitz, Ostran, Muglinan, Michalkowitz, and Hranecznik. In this district Baron Rothschild has both coal-mines and iron-works.

The coal-seams, one of which (Adolph-Flötz)

is about 25 feet in thickness, are included in the Upper Carboniferous series, and repose upon Flötzleerer Sandstein (Millstone Grit), Posidonomya shale, and Carboniferous Limestone.

Another coal-district is that of Rossitz and Oslawan, extending for several miles in a nearly N. and S. direction, and bounded on the west by gneiss, and on the east by syenite. The base of the formation is here a red conglomerate resting on the gneiss, and the Carboniferous rocks are overlaid towards the east by strata referable to the Permian formation (Unteres Rothliegendes).*

Hungary.—There are small coal-fields in several parts of Hungary belonging to the Secondary and Tertiary periods.

Of the former are those of Oravitza, of Berzaska, and Eibenthal, near the northern banks of the Lower Danube; and Peterwardein and Fumfkirchen near Pest. The coal from these places is a kind of semi-anthracite belonging to the Lias formation.

The coal of Gran, north of Pest, is of Tertiary age, and is of the variety known as "brown coal."

* "Die Steinkohlen Deutschlands," etc., vol. i., chap. viii.

At Eibenthal, there are several seams, one of which is 20 feet in thickness. The strata are in a nearly vertical position, and crop out along the sides of the wooded valleys. There is abundance of coal in Hungary for the supply of the railways and steamers on the Daunbe, besides the manufacturing and domestic uses now anually increasing.

Spain.—The coal-field of Asturias in the valley of Quiros, is one of great economic value, though as yet only partially developed. It lies a short distance to the south of Oviedo, and has an area of about 14,826 acres.* The strata containing the beds of coal belong to the Carboniferous system, and repose upon Carboniferous limestone, which rises into a high range of hills to the N.E., E., and S. The beds are thrown into high angles varying from 50° to 70°, and strike in approximately north and south directions. Towards the south, the hilly nature of the ground, and the deep valleys by which it is intersected, offer great facilities for economic working of the coal by means of adits. There

* "Report on the Coal-field," by G. Heim (1860), for an inspection of which I am indebted to Prof. O'Reilly, M.R.I.A. This report gives full and elaborate details of the minerals of the district.

are fifty distinct workable seams from 16 inches to 6 feet in thickness; and the coals belong to three classes, viz., anthracite, semi-bituminous, and bituminous.

M. D'Orbigny states that the thickness of the coal-formation of Asturias is 4,000 mètres; and in the lower part consists of alternating beds of coal and marine strata.* M. Charles Barrois, of Lille, has recognised similar divisions to those of France and of England, including representatives of the "Gannister Beds," with *Anthracosia*, *Bellerophon*, etc. Fossil plants of the genera *Calamites*, *Sigillaria* with the root (*Stigmaria*), and *Neuropteris heterofilia* (Brong.), have been recognised.†

M. Shultz, Director-General of Mines, states that the coal-basin of the centre of the Asturias forms a most extensive district, having more than sixty seams of coal, generally of the best quality, approaching to a vertical position, and extending several leagues from west to east. The eastern limit of the coal-tract appears to be Santander; and westward, probably Oviedo. The strike of the rocks is parallel to the axis of

* "Cours Élém de Palæont.," p. 343.

† Heim, *supra cit.*

the Pyrenees; and near the eastern extremity of the range, on the southern flanks north of Ripoll, coal is extracted from beds which would appear to be an extension of those which yield that mineral in Asturias.

In Eastern Spain, there are also important coal-fields in the provinces of Teruel and Castellon de la Plana, and smaller tracts in the valley of the Guadaloupe and in Catalonia. In the province of Teruel they form three productive coal-fields, the strata attaining a thickness of more than 1,600 feet, as shown by M. Coquand.* There are ten beds of workable coal, lignite and jet, which are all being worked to some extent. The whole of the series has been shown to belong to the Lower Cretaceous system, at the base of the Neocomian, and is identified by Prof. J. W. Judd with certain strata occurring at Punfield Cove, in the Isle of Purbeck, and by him termed the "Punfield formation." †

Russia.—The coal-fields of Russia are considered by Sir R. I. Murchison to belong to the

* Bull. Soc. Geol. de France, 2 sér. t. xxiv. p. 144 (1868). See also Carte Geol. d. l'Espagne et du Portugal, par MM. De Verneuil et Collomb. 1864.

† Quart. Journ. Geol. Soc., vol. xxvii. 207 (1871).

Lower Carboniferous period.* They are included in a set of strata which has a very extensive range, but is only at intervals productive of valuable coal-beds. These Carboniferous rocks form a narrow band along the western base of the Ural Mountains, from the Arctic Sea to lat. 51° S., plunging generally at high angles towards the west, and containing coal, here associated with sandstones, representing probably the "Millstone Grit" of England. On reaching the river Ural, they are concealed beneath the Permian formation, which laps over their edges; but they re-appear again in Central Russia, occupying large areas in the governments of Riazan and Moscow, and stretching northwards to the White Sea, a distance of nearly 900 miles. Throughout this region they are only locally productive.

I am indebted to M. Louis Aguillon for the following account of the distribution of the Russian coal-tracts:—

1. *Central Russia.*—Governments of Tould, Kaluga, Rjasan, and Moscow.

Carboniferous Limestone formation.	White limestone with *Spirifer Mosquensis.*
	Yellow limestone with *Productus gigas*, *P. costatus*, and fish remains.
	Sandstones and shales with coal-seams.

* "Russia and the Ural Mountains," vol. i., p. 69.

2. *Southern Russia.*—Basin of the Donetz, and the territory of the Don Cossacks. Coal-seams in sandstones and shales subordinate to the Mountain Limestone ("Calcaire de Montagne"); but there may also be beds of true Coal-measures in the district.
3. *Siberia.*—Great basin of Kousnetsk in the Altai. Coal-measures with beds of coal.
4. *Caucasus.*—(Txwibul).—Coal in strata subordinate to the Jurassic formation (terrain Oolithique).
5. *Oural.*—Districts of Swewolosky and Lasareff. *c*, Limestone with *Spirifer*; *b*, sandstone and shale with coal; *a*, sandstone with *Productus*.

The coal-seams of the Moscow-basin are generally impure, pyritous, and fragile, and seldom equal in quality to the best lignites of the Tertiary age in the Alps. Some of the seams are from 3 to 6 feet in thickness, and, as they outcrop in natural ravines, are easily accessible. The coal-field between the Dnieper and the Don, north of the Sea of Azof, is considered by Sir R. Murchison to be by far the most valuable in Russia.* This tract has a length from W.N.W. to E.S.E. of 230 miles, and its transverse diameter is 100 miles. Its total area is about 11,000 square miles. It contains many valuable beds of coal, which dip under, and are over-

* An excellent map of this coal-field, exhibited at South Kensington in 1876, has been constructed by General C. v. Helmersen, showing the coal-seams and numerous flexures.

spread to the north-east by, Cretaceous rocks, and to the south-west by Permian limestone (Zechstein), under both of which formations the coal may at some day be mined, as is the case in Belgium and England. The most valuable seams occur at Lugan and Lissitchia-Balka.

It is a most remarkable circumstance in connection with the Donetz formation, that the same beds of coal, from being highly bituminous in the western parts of this coal-field, pass by imperceptible gradations into anthracite in the eastern parts, in a manner analogous to that of the South Wales coal-field in our own country. In the western or bituminous districts, the coals are associated with limestones containing *Spirifer Mosquensis.* Towards the centre these calcareous beds tail out, and are replaced by beds of sandstone and shale, which become hardened and altered as the coal-seams become anthracitic.

On the whole, it would appear from the copious details and sections contained in the elaborate work of Murchison and his companions, that the coal-fields of the Russian empire, certainly of enormous area, are in some parts highly productive, and, if vigorously opened up, are likely to become of great economic value. The whole

coal-producing series, also, appears to be of an earlier date than the true Coal-measures of England; the greater part of the beds of coal being contained in the Carboniferous Limestone-series.

Anthracite of Switzerland, Savoy, and Italy. Dr. Oswald Heer has described the anthraciferous deposits, which are worked to a considerable extent as fuel for locomotives of the Italian and Swiss Railways. They occur amongst the Western Alps, including towards the west and south the valleys stretching through Savoy into Dauphiné; and in an easterly direction into the Canton of Glarus.*

The anthracite is associated with schists and sandstones containing plant remains of true Carboniferous genera; and an examination of these has convinced Professor Geinitz that the anthracite beds are an altered Carboniferous product, contrary to the opinion of some observers, who have referred them to the Lias formation, on the ground of their being immediately overlaid (or underlaid by inversion) by shales with belemnites. The presence, however, of such examples as *Calamites cannæformis*, *C. Suckowii*, *Asterophyllites equisetiformis*, etc., seems to

* "Urwelt der Schweiz," 1865.

place their Carboniferous affinities beyond question.*

Similar deposits with anthracite occur in considerable force at Demonte, in the valley of the Stura, in the Alps of Piedmont, consisting of schists with Carboniferous ferns and *Lepidodendron*. They have been described by Chevalier W. P. Jervis, who regards them as likely to prove of great economic value to the young kingdom of Italy.†

Poland.—At the south-western extremity of Poland, and within a short distance of the confines of the Russian, Austrian, and Prussian States, is situated a small but extremely productive coal-field. It contains three known coal-seams, the middle one of which is no less than 16 yards in thickness, and is probably the thickest bed of mineral fuel in Europe. It is worked from the outcrop in mines near the village of Dombrowa, and has the following composition:—

Carbon	50·38
Volatile matter	47·23
Ashes	2·39
	100·00

* Die Steink. Deutsch., vol. i., 340.

† *Mining Journal*, Aug. 1875.

This coal-seam dips from the outcrop at an angle of from 12° to 32°.

The two remaining seams vary from 3 to 9 feet in thickness, and differ from the main seam in having a smaller percentage of volatile matter.

The area of the coal-field is supposed to be about 16 square miles. The formation belongs to the true Carboniferous period, reposing on Silurian rocks, and dipping under Tertiary strata.*

* For this account of the coal-field of Poland, I am indebted to Captain A. Antipoff, of the Russian Engineers.

CHAPTER II.

INDIA.

THE approach towards completion of the surveys of the coal-fields of India by the Government Geological Surveyors, under the late Dr. Oldham, and his successor, Mr. H. B. Medlicott, and the publication of an able series of Reports to accompany the maps on which the details are portrayed, puts us in possession of accurate information regarding each coal-field individually.

The general result of these surveys is to show that there are very large tracts stored with coal in northern India, chiefly in the valley of the river Damuda; which, as the Messrs. Blanford* have suggested, were once connected in one continuous area, but are now dissevered, owing to large displacements of the strata and denudation. Of these the names and approximate areas are given in pages 394-5.

* "Report on the Talcheer Coal-field," Mem. Geol. Surv. India, vol. i., part 1.

The Coal-beds of India are chiefly found in that great series of conglomerates, sandstones, and shales now comprehended under the name of "the Gondwana System," and the following is the classification of this group as at present recognised by the Geological Survey of India:—*

MESOZOIC	Upper	Cutch and Jabalpur Rajmehal and Mahadeva	Thickness 11,000 feet.
PALÆOZOIC	Lower	Panchet Damuda; Ranigunj or Kamthi Ironstone Shales and Barakar Kaharbari and Talchir	13,000 "

Geological Age.—The geological age of the coal-bearing formations of India has for many years been a subject of controversy. The subject has been ably discussed by the late Dr. Oldham,† on the evidence which had come to light at the time he wrote.

Having shown that the upper Damuda, or Rajmahal group, characterized by the abundance of Cycads, and comparable with the coal-formation of Cutch, is in all probability referable

* For the information here given I am largely indebted to Messrs. Medlicott and Blanford's "Manual on the Geology of India," and to a paper "On the Coal-fields and Coal-production of India," by Mr. V. Ball, of the Geological Survey of India, published in the Scientific Proceedings of the Royal Dublin Society, 1880.

† Mem. Geol. Surv. India, vol. ii., p. 298.

to the "older Mesozoic period," he next discusses the relations of these beds to the underlying Damuda group containing the beds of coal, and shows that, while there is a complete break or unconformity between the two groups, there is also a remarkable change in their respective floras, and an entire absence of Cycads so abundant in the overlying group. The following are the genera determined from the Damuda coal-formation :—

Sphenophyllum	3 species
Vertebraria	2 ,,
Phyllotheca	2 ,,
Cyclopteris (?)	1 ,,
Pecopteris	4 ,,
Glossopteris	5 (?)
Calamites	1 ,,
Schizoneura	2 ,,

After comparing this flora with that of the coal-formation of New South Wales, he finally comes to the conclusion that the Damuda series belongs to some portion of the Upper Palæozoic epoch of European geological sequence, or the lowest portion of the Mesozic division. In fact, according to Dr. Oldham, we may possibly find hereafter that it represents that great interval

indicated by the marked separation and hiatus between the two series in other countries.*

On the other hand, more recent investigations have shown that *Glossopteris*, the genus of ferns which had formerly been supposed to be characteristic of the Lower Gondwana beds has been found to occur in the very highest beds of the upper series,—the Jabalpur beds; while several species of Cycadaceous plants, which order was supposed to be restricted to the upper groups, have been since found to exist in the lower or Damuda group; thus to a great extent, and as far as the flora is concerned, the whole Gondwana system seems to be united into one, notwithstanding physical discordances.

But the difficulties do not end here; for as regards some of the newer groups, the marine faunas, where present, do not always point to the same conclusions as the floras. The matter has been thus summarized by Mr. H. B. Medlicott in his Annual Report for 1876:—

"The facts of our Gondwana rocks are certainly puzzling to systematists. On the west, in Kach we have the flora of the top Gondwana group, which has a Bathonien *facies* associated

* *Ibid.*, p. 333. Dr. Oldham stated in 1874 to myself, that he adhered to these views.—E. H.

with marine fossils of Tithonien affinities; while on the S.E., the Trichinopoli beds, with a *flora*, so far as known, like that of the Rajmahal group, which is taken to be Liassic, have been described by Mr. H. Blanford as overlaid in very close relation by the Otatoor group, the *fauna* of which has been declared upon very full evidence to have a Cenomanien (Upper Cretaceous) *facies*."

From the above it will be apparent that any attempt to correlate the ages of the great coal-bearing rocks with those of Europe and Britain, must be considered futile. This great group of lacustrine and fluviatile beds appears to have been formed under geographical conditions entirely dissimilar to those which prevailed in the more westerly regions of the northern hemisphere, and we may rest content with the view adopted by the Authors of the "Manual of the Geology of India," that the whole series of beds from the Talchir boulder beds to the Umia beds of Kach (Cutch) have been deposited during a period ranging from the Permian to the Upper Jurassic of Europe.*

* Dr. Feistmantel, Palæontologist to the Geological Survey of India, regards the age as ranging from the Trias to the Lower Oolite or Jurassic; the Cutch beds being of this latter.

Areas of the Gondwana Rocks.—The following estimates of areas of the coal-bearing beds, and those which may be considered to overlie coal-bearing beds, has been drawn up by Mr. Hughes, of the Indian Survey:*—

Godavari and affluents . . .	11,000	square miles.
Sone	8,000	,,
Sirguja and Orissa, etc. . . .	4,500	,,
Assam	3,000	,,
Narbuda and affluents . . .	3,500	,,
Damuda	2,000	,,
Rajmahal area	300	,,
Unsurveyed, etc.	2,700	,,
	35,000	,,

List of Separate Coal Fields.

(THOSE IN CAPITALS ARE WORKED.)

Bengal.

1. Rajmahal Hills . .	North of Damuda River.	
2. Birbhum . . .		
3. Deogurh . . .		
4. KARHARBARI . . .		
5. RANIGUNJ . . .	Damuda Valley.	
6. Jeriah		
7. Bokaro		
8. Ramgurh . . .		
9. Karanpura, N. . .		
10. Karanpura, S. . .		
11. Chope	West of Damuda Valley.	
12. Itkuri		
13. Aurunga . . .		
14. Hutar		
15. DALTONGUNJ . . .		

* "Records,' vol. vi., p. 65.

16. Tattapani	Sone and Mahanadi Valleys.
17. S. Rewah and Sohagpur .	
18. Jhilmilli . . .	
19. Bisrampur . . .	
20. Lukanpur . . .	
21. Rampur. . . .	
22. Raigurh and Hingir .	
23. Udaipur and Korba .	
Orissa.	
24. Talchir	

Central Provinces.

25. Mopani	Satpura Region.
26. Tawa	
27. Pench	
28. Bandar	Godaveri Valley.
29. Wardha or Chanda. .	
30. Kamaram . . .	
31. Singareni . . .	

Sikkim.

32. Sikkim.

Assam.

33. Makum	Valley of the Bhramaputra.
34. Jaipur	
35. Nazira	
36. Jangi	
37. Disai	

In the above list, localities, chiefly situated in the north-west provinces where Tertiary coal occurs, but not in sufficient quantity to constitute workable coal-fields, have not been included.

Of the thirty-seven separate fields, only five are at present worked with regularity. These

are Ranigunj, Karharbari, and Daltongunj in Bengal, and Mopani and Wardah in the central provinces.

I now proceed to give a short description of the more important coal-fields, referring the reader for fuller information to the works already quoted.

Ranigunj.*

This field is situated on the rocky frontier of Western Bengal, at a distance of 120 miles from Calcutta.

The groups represented with their respective thicknesses are as follows :—

Upper Panchet or Mahadeva . .	500	feet.
Panchet	1,500	,,
Ranigunj	5,000	,,
Ironstone shale	1,400	,,
Barakar	2,000	,,
Talchir	800	,,
Total	11,200	,,

The Ranigunj coal-field is the largest and most important of the areas in which coal is worked in India. Its proximity to the main line of railway, and also to the port of Calcutta, tends to give it pre-eminence over other less favourably situated localities. The total area of coal-

* Blanford, "Memoirs Geol. Surv. of India," vol. ii.

bearing rocks which is exposed is about 500 square miles; but it is possible that the real area may be even double that, since on the east the rocks dip under, and are completely concealed by, alluvium. Throughout this area a central zone includes the principal mines, and the chimneys which dot this tract constitute it "the black country" of India. In the year 1774, coal was known to occur there; and so long ago as 1777, was actually worked. In 1830, several collieries of considerable extent had been opened out, and were, we have reason to believe, in a flourishing condition.

In 1872, forty-four mines were at work, nineteen of which turned out upwards of 10,000 tons each yearly. In 1879, there were six principal European companies engaged in the extraction of coal, while many minor firms and native associations contributed to swell the amount raised. Many of the seams are of considerable thickness; one being worked reaching 40 feet of coal. As a rule, the thick seams do not contain the best coal. Compared with ordinary British coal, those of India are much inferior in working power; still they are capable of generating steam for locomotive and other engines. In 1868, the output from the Ranigunj

mines was 564,933 tons; in 1872, it fell to 322,443 tons; but, as we learn from the speech of the Lieutenant-Governor of Bengal, the quantity raised in 1879 amounted to 523,097 tons.

The coal which is fairly representative of Indian coals, may be described as non-caking, bituminous, and composed of alternating lamina of bright jetty and dull earthy appearance. The average of thirty-one assays of samples from different mines has given the following results:*

Moisture	4·80
Volatile matter	25·83
Carbon (fixed)	53·20
Ash	16·17
	100·00

The cost of steam coal at the pit's mouth is from $2\frac{1}{2}$ to 3 rupees, say 5 to 6 shillings, per ton. In Calcutta the cost is 14 to 16 shillings, and in Lahore about £5.†

North Karanpura Coal-field.—This coal-field is situated at the head of the Damuda valley, between 84° 51′ and 85° 30′ E. long., and 23° 37′ and 23° 57′ N. lat., and covers an area of 472 square miles. From the Report of Mr. T. H.

* Records, Geol. Surv. Ind., vol. i., p. 155.

† Mr. V. Ball, *supra cit.*

Hughes,* of the Indian Survey, it appears that there are numerous seams of coal, giving a total vertical thickness of 35 feet; calculated to yield about 8,750 millions of tons. A specimen from the larger of the Gondalpura seams gave, on being assayed, the following results:—

Carbon 64·5, Volatile matter 27·0, and Ash 8·5.

South Karanpura Coal-field.—This has an area of about 72 square miles, and a thickness of 70 feet of coal, with an estimated quantity of 75,000,000 tons.

The situation of these coal-fields, in a deep valley surrounded by hills, renders it improbable that the ample resources of this district will become fully utilized. Iron-ores are abundant.

Aurunga.—This field is situated in the district of Lohardugga, to the west of the sources of the Damuda, in the valley of the Koel, a tributary of the Sone. The area is 97 square miles, and the groups represented are:—

Mahadeva	1,000 feet.
Panchet	700
Ranigunj	1,000
Barakar	1,500
Talchir	300
	4,500

* Mem. Geol. Surv. India, vol. vii., part 3, with map.

There are numerous coal seams, some of good thickness; the estimated amount of coal which they contain being 20,000,000 tons.

The following average proportions of constituents derived from the assays of seven samples from different localities indicate a very poor quality of fuel:—

Moisture	6·7
Volatile	29·3
Carbon	36·5
Ash	27·5
	100·0

Valuable and extensive deposits of iron ores and limestones occur in, and near, the coal-field. The inferiority of the coal is to be lamented, as should a project for manufacturing iron in this district ever be adopted, fuel, it seems probable, will have to be obtained from some of the neighbouring fields.

Bokaro Coal-field.—This is the third in importance amongst the coal-tracts of the Damuda valley. From Mr. T. W. Hughes' Report we find that it contains several seams of valuable coal from the "Barakar beds," capable of yielding about 1,500 millions of tons. The most valuable portion of this field lies between the

river Koonar and the eastern boundary. Beds of ironstone are also present.*

Jeriah Coal-field.—This tract lies about 170 miles from Calcutta, along the Damuda valley, and extends from east to west for a distance of 18 miles; its greatest breadth is 10 miles. Mr. Hughes, in his Report, states † that in a series of beds of about 6,000 feet in thickness, there are beds of coal having a combined thickness of about 80 or 100 feet, the thicker seams being in the lower part of the Damuda series. Some of the coal is of good quality, especially that of the "Barakar beds." Dr. Oldham estimates the possible yield of this coal-field at 465 millions of tons, and adds, "whatever the margin of error may be, the facts are sufficient to prove the existence of a very large amount of good fuel in this Jeriah coal-field, which at some future period will be found most valuable." ‡

Ramgurh Coal-field.—This coal-field also lies in the Damuda valley, between the meridian of 85° 30′ and 85° 45′ E. long. From the Report of Mr. V. Ball, it appears to have an area of about 40 square miles. The coal in the eastern part

* Mem. Geol. Surv. India, vol. vi., part 2.

† *Ibid*, vol. v., p. 230.

‡ Mem. Geol. Surv. India, vol. v., p. 336.

of the district occurs generally in thick seams; but the quality is so variable, and there are such frequent alternations with bands of stony shale, that Mr. Ball forms a low estimate of the economic value of this portion. In the western extension of the field, where the seams are of better quality, they are much broken and crushed, owing to numerous faults and flexures of the strata.*

Karharbari Coal-field.—This coal-field is one of those which lie beyond the limits of the valley of the Damuda. The coal-beds are, however, referable to the "Damuda series," and from the superiority of their quality, and owing to their position with reference to the East Indian Railway, and the large towns west of Dinapore, are likely to become of great economic value. The area of the field is only 8 square miles, and its general structure that of a basin;† while some of the coal-seams reach a thickness of 14 to 16 feet, but vary rapidly in this respect. Mr. Hughes estimates the yield of this tract at 80 millions of tons of available coal.

The Deoghur Coal-fields.—There are three little tracts grouped by Mr. Hughes, who has

* Mem. Geol. Surv. India, vol. vi., part 2.

† Mr. T. W. Hughes.—*Ibid*, vol. vii., part 2.

surveyed them, under this name, lying between long. 86° 37′ and 87° 5′ E. to the north of the Barakar river. They do not require special notice, as they are economically unimportant.

Raigarh and Hingir Coalfield.—This coalfield, for an account of which we are indebted to Mr. V. Ball,* is situated on the south-west frontier district of Bengal, between the Ebe and Mahanadi rivers, north-west of Sambalpur; it is estimated to have an area exceeding 5,000 square miles, and is largely concealed by a covering of the newer "Hingir Group" of rocks. Several seams of coal have been noticed of fair promise, especially one at Dibdorah, which is 6½ feet in thickness and easily accessible. According to analyses of six seams given by Mr. Ball, the proportion of ash varies from 13 to 37 per cent., while the quantity of volatile matter is large. Iron ore is also present in considerable amount, in two or three zones in "the Barakar Group."

In the Chanda district, valuable seams of coal have been proved, one bored to in 1869 being 30 feet in thickness.†

* Records Geol. Surv. Ind., No. 4 (1875 with map).

† "Rep. Coal-Commission," vol. iii., p. 237.

Nerbudda Coal-fields.—This coal-field includes a considerable tract in Western India, lying in part along the valley of the Nerbudda River, and containing both coal and iron-ores. The district has been explored by several observers, the latest of whom, Mr. Medlicott, has drawn up a Report on behalf of the Geological Survey.* The actual extent of country over which these mineral deposits may be supposed to range has not been precisely determined, owing to the want of actual mining operations; but coal-seams of good quality and thickness have been observed along the banks of the Sitariva, the Tawa near Salyia, the Mahanuddi and Johilla rivers; and Mr. Medlicott states that unquestionably from some of these localities large supplies of good coal might be obtained. The strata in which the coals occur belong to the Damuda series.

The Bisrampur Coal-field lies in the eastern portion of Central Sirguja, and has been reported on by Mr. V. Ball of the Geological Survey. It occupies an area of about 400 square miles, and is drained by the Mahan River and its tributaries, along whose banks sections of the strata with coal-seams are sometimes found. Owing, however, to the thick deposit of diluvial

* Mem. Geol. Surv. India, vol. ii.

matter which covers the district, its mineral resources are but little known, though Mr. Ball considers that good coal is unquestionably present.*

Godaveri Valley.

Fandar Coal-field, etc.†—This field is situated near the village of Chimur, thirty miles north-east of Warora, in the Chanda district. The existence of coal-measures under a small tract of Kamthi beds, 5 to 6 miles square, has been proved by boring. Three seams of coal have been ascertained to exist, and these have a maximum total thickness of 38 feet. The coal is similar in character to that of Warora.

Wardah or Chanda Coal-field, etc.‡—This coal-field constitutes the northernmost extremity of an immense tract of Gondwana rocks, which extend for about 285 miles from north-west to south-east in the valleys of the Wardah Pranhita, and Godaveri basins.

The group of rocks exposed is as follows :—

* "Records of the Geol. Surv. of Ind.," No. 2, 1873.

† Hughes, "Mem. Geol. Surv. of Ind.," vol. xiii., pp. 145-154. "Manual," vol. i., p. 226.

‡ Hughes, *loc. cit.*, p. 145.

Upper Gondwana.

Kota Maleri	1,500	feet.
Kamthi	2,500 to 2,3000	„
Barakar	250	„
Talchir	250	„

Any attempt to give an idea of the distribution of coal-measures throughout this area, without employing a mass of detail, would certainly fail. I shall therefore confine myself to quoting Mr. Hughes' estimate of the amounts of coal in several of the particular tracts where its existence has been proved by actual outcrops or by borings.

	Actual Quantity. Tons.	Amount Available. Tons.
Warora basin	20,000,000 . .	14,000,000
Ghugus	90,000,000 . .	45,000,000
Wun	2,100,000,000 . .	1,500,000,000
Between Wun and Papur . .	105,000,000 . .	50,000,000
Between Junara and Chicholi .	150,000,000 . .	75,000,000
Sasti and Paoni basins . .	60,000,000 . .	30,000,000
	2,525,000,000	1,714,000,000

The following assays will serve to convey some idea of the quality of the coals :—

	Warora.	Pisgaon.	Ghugus.*
Fixed Carbon .	45·4 .	65·1 .	45·61
Volatile matter .	26·5	19·2 .	33·49
Water . . .	13·9 .		
Ash . . .	14·2 .	15·7 .	20·90

* Average of sixteen assays.

In Mr. Hughes' "Memoir," assays of samples from other localities are also given.

The Warora coal is deficient in fixed carbon, a larger per-centage of which is essential where great heating power is required. It is also deficient in combustible volatile gases. Pisgaon coal, however, contains a more considerable proportion of fixed carbon, viz., 65·1 per cent.

The only pits in this wide area which are worked are at Warora, where the out-turn was, in 1878, 1,500 tons per week. The great outlay by the Government in connection with the exploration and testing of the field has not yet been nearly repaid, the cost of extraction being heavy.*

A special branch line conveys the Wardah coal to the Nagpur branch of the great Indian peninsular railway, by means of which it is distributed both for use on this line, and for factories.

Several other small areas of coal-bearing rocks occur further down the course of the Godaveri valley at Dumagudium, Mudavaram, etc., etc., to which much interest has attached, as it was hoped that they might yield a supply of coal

* £600,000 is stated to have been already expended at Warora alone at the time Mr. Hughes' Report was printed.

for the Madras Presidency, but the prospect of their doing so does not appear to be a good one.

*Kamaram.**—This name has been given to two small fields situated near the village of Kamaram, which lies forty miles, a little north of east, from Warangul in the Hyderabad territory.

The larger one is six miles long, by about one mile broad; it consists of Talchir, Barakar, and Kamthi rocks. It includes two coal seams of fair quality, measuring respectively 9 feet and 6 feet. The available coal is estimated at 1,132,560 tons, and it is stated to be equal to the average coal of the Wardah fields. Its position is unfavourable to its development, water carriage being too far distant.

The smaller field, which is about half a square mile in area, is of no importance.

Singareni Coalfield.†—This field is situated near the village of Singareni in the Hyderabad territory, about thirty miles to the south-east of the Kamaram field. Its area is nineteen square miles, the coal-measures being found throughout about eight square miles. One coal seam was discovered, but being much concealed, its thick-

* King, "Records Geological Survey of India," vol. v., p 50. "Manual," vol. i., p. 240.

† King, *tom cit.*, p. 65. "Manual," vol. i., p. 241.

ness was not ascertained; an assay of a sample from it gave :—

Fixed Carbon	62·4
Volatile	22·6
Ash	15·0
	100·0

Additional seams, one of them 21 feet thick, have since been proved by boring.

This field may possibly become of some economic importance, as there is a prospect of a railway being constructed at no great distance from it.

Sikkim.

*Darjiling District.**—This field occupies a narrow zone, which stretches along the foot of the Himalayas, from Pankabari to Dalingkote. The rocks are Barakar beds probably, which have been much crushed and tilted, dipping at angles of from 40° to 90° to N.N.E., or towards the main mass of the hills. Frequently the sandstones have been converted into quartzites, and the shales into splintery slates. Much of the coal is in the condition of powder, and some

* Mallet, "Memoirs Geological Survey of India," vol. xi. "Manual," vol. i., p.

of it has assumed the character of graphite. The effect of the compression has been to reduce it by removal of the volatile portions to the condition of an anthracite. Some experiments were made with a view to utilizing it in the manufacture of artificial fuel, but the process found to be requisite was too expensive, and the difficulty of boring in these crushed rocks is so great as to render it improbable that this coal will ever be commercially available.

One seam is 11 feet in thickness. The average of five assays of the coal gives the following composition :—

Carbon	70·66
Volatile	9·20
Ash	20·14
	100·00

Into a description of the complicated geological relations of these beds with those forming the adjoining mass of the Himalayas, I do not now propose to enter. Mr. Mallet has arrived at the somewhat startling conclusion that the coal-measures are younger, and underlie the highly metamorphosed rocks of the outer slopes. To do justice to his arguments would require more space than is at present available for the purpose.

The fact that this locality is the only one north of the Ganges where Gondwana rocks occur, is of great interest in connection with any discussion as to the early relations which existed between the Peninsular and Himalayan regions, and indeed the formation of the Himalayas themselves.

ASSAM.*

Five distinct coal-fields exist in the valley of the Bhramaputra, in the province of Assam. They are distinguished by the following names:—33, Makum; 34, Jaipur; 35, Nagira; 36, Janji; 37, Disai.†

It will be convenient in this abbreviated account to treat of them collectively.

Some uncertainty exists as to the age of the rocks, but the balance of evidence seems to favour the view, that it is middle Tertiary (Miocene), and therefore distinct from the Cretaceous and Nummulitic coals of the Khasi hills.

The coal differs from that of the Indian coal-fields in having a homogeneous structure, and in

* Mallet, "Memoirs Geological Survey of India," vol. xii., pt. 2. "Manual," vol. ii., p. 701.

† The numbers refer to those given, p. 395.

the absence of lamination; the average of the assay of twenty-three samples gave :—

Moisture	5·0
Carbon	56·5
Volatile	34·6
Ash	3·9

This shows a high quality of fuel as compared with Indian coals.

The opening up of these fields is a point of the highest importance, since at present coal is carried 1,000 miles from Bengal for the navigation of the Bhramaputra; thus causing a tenfold increase on the prime cost.

It is possible that some of the coal of the Khasi hills above alluded to, may prove of value hereafter; but the same does not, so far as is known, seem probable in reference to the Tertiary coals of the north-west provinces, although hopes in that direction have often been expressed; and a project for the exploration of one of these deposits has, I understand, recently assumed a tangible form, a company having been formed, the result of whose operations will be watched with interest.

Salt-Range, Punjab.—Beds of coal and lignite of inferior quality occur near Bhaganwala, Pid, and Samundri. They belong to the Jurassic

and Tertiary period, and are described in detail by Mr. Wynne in his valuable memoir on the Salt-Range.*

Summary.—From the above brief description of a few of the coal-fields of British India, taken from the careful and elaborate reports of the Government Surveyors, which are accessible to all, it may be gathered that Northern India has all the materials for the development of commercial and industrial pursuits. The valley of the Ganges, navigable for such great distances inland from the ocean, and now traversed by lines of railway, has also enormous stores of coal and iron—those materials which have been the source of the wealth of Great Britain itself. It is also a cotton-growing country, and there is therefore no apparent reason why cotton might not to a larger extent be manufactured where it is grown. With such advantages, Northern India *may* become a great manufacturing country. Whether it *will* become so is a question which will be determined on moral and social grounds; depending on the enterprize, perseverance, and intelligence of the people themselves.

* "On the Geology of the Salt-Range, Punjab," Mem. Geol. Survey, Ind., vol. xiv. These deposits were previously reported upon by the late Dr. Oldham for the Indian Government. The Report is not encouraging.

CHAPTER III.

COAL-FIELDS OF CHINA, AUSTRALIA, AND NEW ZEALAND.

China.—The laborious researches of Baron von Richthofen, the enterprising traveller, together with the accounts received from time to time through other sources, leave no doubt that there are large deposits of coal in this great empire. The provinces of Hoonan and Shansi, lying to the south of the Yang-tse-Kiang, are richly stored both with coal and iron. In the latter province the Baron came upon a region which he describes as "one of the most remarkable coal and iron districts in the world."* He considers it to be in extent considerably greater than that of Pennsylvania. These vast resources are not utilized by the natives, owing to unskilfulness in mining, and chiefly to the absence of roads. Another of these districts lies near the city of E-u, in the prefecture of

* From Report forwarded to the Foreign Office, and quoted by Sir. R. Murchison in the Anniversary Address to the Roy. Geog. Soc. London, 1871.

King Hua (lat. 29° 15′ N., long. 119° 46′ E.) The coal is here worked in pits from 300 to 500 feet in depth, and the mines are opened out into galleries branching off into the seams at successive stages in the descent.* The mineral is also worked in the cliffs of the Pe-Kiang river at Tingtih, by means of adits driven into the side of the hill at the outcrop of the coal-seams; and lastly, at a place five miles from the city of Whang-shih-Kang on the river Yang-tse-Kiang, an account of which is recorded by Mr. Oliphant.†

The working of coal in China dates probably from a very ancient period. Our earliest notice is by the celebrated traveller, Marco Polo, towards the close of the 13th century.

As regards the geological age of the coal-formations of China, the evidence which we possess leads to the conclusion that they are more recent than the Carboniferous, and probably of Mesozoic age. Remains of cycads are abundant, and have been collected by Mr. R. Pumpelly;‡ on the other hand, the characteristic Carboniferous genera and species are apparently

* Rev. R. H. Cobbold, Journ. Geol. Soc., vol. xii.

† "Lord Elgin's Mission to China and Japan," vol. ii., p. 389.

‡ American Journal of Science, Sept. 1866.

wanting. It seems, therefore, not improbable that the newer Indian and Chinese carbonaceous deposits are of the same, or nearly the same, geological age.

Malaysia and Japan.—That magnificent group of islands lying between the Indian and North Pacific Oceans, seems to be as rich in the mineral treasures of the past as it is in the vegetable productions of the present. Besides gems, and metallic ores in abundance, including iron, which yields the unrivalled Japanese steel, several of these islands contain strata stored with coal. And when we regard the geographical position of these islands, lying on the confines of the Eastern hemisphere, and in the track of vessels trading between America and Asia, the economic value of these sources of fuel can scarcely be over-estimated. It was on this account that the American expedition to Japan kept steadily in view the establishment of depôts for coal on several points on the coast of those islands, for the supply of American steam-vessels.* With a similar object, the Indian Government have given attention to the supplies of coal known to exist in Borneo, and have been successful in inducing the chiefs to form depôts of coal on

* "American Expedition to Japan."

the coasts. It is also satisfactory to learn that the trials made both in New York, Calcutta, and in the steam-vessels themselves, of samples of coal from these islands, are very favourably reported.

In Japan, coal-mines are worked in the districts of Kiusin and Niphon; and the testimony of Kæmpfer regarding its abundance is corroborated by that of the officers of the American expedition. The Islands of Formosa and Karapty, the latter of which is now appended to the Russian Empire, also contain this mineral in considerable quantity.*

In Borneo, the province of Labuan on the north-west coast abounds in coal, and there is at least one important colliery now in work.† Several beds crop out near the river Gooty, at the north-east of the island. Mr. Bellot

* Atkinson's "Travels in the Amoor."

† At this colliery there are 4 seams.

No. 1	seam	4	feet	6	inches.
,, 2	,,	2	,,	9	,,
,, 3	,,	3	,,	9	,,
,, 4	,,	11	,,	3	,,
Total		22	,,	3	,,

A new colliery is being put down, intended to raise 100,000 tons per annum; as I am informed by Mr. R. M. Smith of Edinburgh (1873).

states that the mineral resembles the best cannel, and burns readily.* It also occurs in Pulo Cheremin, an island at the mouth of the Borneo river.

Mr. J. G. H. Godfrey has described a coal-bearing series of strata at Horimui of considerable extent, best developed in the western part of Japan, and considered on fossil evidence to be of Cretaceous age.†

AUSTRALIA.

The great Anglo-Saxon Empire, which is springing up at the antipodes, seems to have all those mineral resources so necessary to the commercial prosperity of a nation. Amongst these, coal is not the least important; and that it occurs in vast quantities will be apparent from the following brief statements of each of the provinces into which Australia has been parcelled.

Victoria.—The state of Victoria contains carbonaceous deposits, from which coal has already been extracted. The late Government geologist, Mr. Selwyn, was engaged for several years in

* Mr. T. Bellot, Journ. Geol. Soc., vol. iv.

† Notes on the Geology of Japan. Proc. Geol, Soc. Lond. (1877-8).

investigating the mineral resources of this highly-favoured colony, and has prepared very fine maps of the coal-districts. Mr. Selwyn states that if the mass of the coal-bearing strata of Victoria be Oolitic (Jurassic), there are certainly others in the eastern districts of the colony which contain plants of the true *Carboniferous* type, while the beds themselves rest and pass downwards into calcareous rocks with fossils which are nearly all Carboniferous or Devonian forms.* How remarkable, that both here and at our Antipodes, in Britain in the Northern, and Australia in the Southern hemisphere—countries now standing in the relation of parent and child—Nature should have been elaborating mineral fuel during the same eventful period of the Earth's bygone history!

New South Wales.†—This coal-field extends along the coast of the Pacific Ocean from Sussex Haven to Port Stephens, a distance of 200 miles, and inland to the base of the Cordilleras, having

* "Geology of Victoria," Journ. Geol. Soc. London, vol. xvi., p. 145.

† "Mines and Mineral Statistics of New South Wales" (Sydney, 1875), containing reports by Mr. C. S. Wilkinson, Government Geologist, the late Rev. W. B. Clarke, Professor Liversidge, Mr. Mackenzie, Examiner of Coal-fields, and others.

an area of over 15,400 square miles, and contains numerous seams of bituminous, steam, and gas coal, besides beds of "Kerosine," or oil-shale, and of iron-ore. The beds belong to the Carboniferous series, as shown by the late Rev. W. B. Clarke, and are largely charged in their lower part both with fossil shells and plants similar to those of the Carboniferous series of Western Europe and Britain.

The general succession of the strata, according to Messrs. Clarke and Wilkinson, is as follows:—

(*e*)	Wianamatta series, shales with fish *Palæoniscus*, fresh water shells and plants . .	500 feet.
(*d*)	Hawkesbury series, chiefly sandstones with ferns (*Cyclopteris Browniana*) . . .	1,000 „
(*c*)	Upper Coal-measures of Newcastle with plants, etc. (*Glossopteris*, *Sphenopteris*, *Conifers*); 16 coal-seams over three feet in thickness .	480 „
(*b*)	Upper Marine beds, shales, sandstones, and coal, numerous shells, *Productus*, *Spirifera*, Crinoids	350 „
	Lower Coal-measures, shales, sandstones, with similar fossils	100 „
(*a*)	"Lepidodendron Beds," shales, sandstones, etc., with plants, *Knorria*, *Sigillaria*, *Lepidodendron*, resting unconformably on the Devonian rocks.	

The Wianamatta series is said to rest unconformably on the Hawkesbury series, and is pro-

bably of a later geological age; the lower groups (*a* and *b*) clearly indicate an age corresponding to that of the Carboniferous rocks of Great Britain.*

In 1874, 1,304,567 tons of coal were raised and a good deal exported from Newcastle. The output is yearly increasing.

No one has contributed so largely to our knowledge of the coal-resources of New South Wales as that indefatigable explorer, the Rev. W. B. Clarke, recently deceased. I have been favoured by him with a general summary of the results arrived at up to 1861 (since extended), which are of increasing importance to the development of the colonies, as also to the progress of communication by railways, which have sprung into existence since the Exhibition

* Professor McCoy considered the upper plant-bearing beds to be of Jurassic age, and to be stratigraphically disconnected with those bearing coal. Professor J. Morris seems to have held a similar view. On the other hand, the late Professor Jukes, writing in 1850, three years after the publication of Prof. McCoy's valuable papers, expressed his opinion that the whole series was "one great continuous formation." Dr. Oldham, in reviewing the relations of the Coal-formations of New South Wales and of India (Damuda group), came to the conclusion that they are identical in age, *i.e.*, at the confines of the Palæozoic and Mesozoic epochs. Mem. Geol. Survey of India, vol ii., p. 333.

of 1855, and to steam navigation, now rapidly advancing, as well as to manufacturing establishments rising around. The following are extracts from Mr. Clarke's summary:—*

"In the year 1847, the author of this notice stated (in evidence before a Committee of the Legislative Council), that he had then obtained acquaintance with the existence of Carboniferous formations over from 17,000 to 18,000 square miles on the eastern side of the Colony, between 32 degrees and 35 degrees South. Since then, his own experience has been much enlarged during his explorations of Australia; and, coupling his present actual knowledge with the information derived from other explorers, he is now enabled to state that, compared with its Gold-fields, the Carboniferous portion of this territory is of infinitely greater importance than was at that time supposed."

On the East coast of New South Wales, the Carboniferous formation presents itself with little interruption, except from extensive dykes of trap (of which the basaltic dykes strike N.E., and the greenstone dykes, which are well exemplified on the coast at Newcastle, strike N.W.), from between 31 deg. 30 min. South, to at least 36

* Dated, "St. Leonard's," 19th Oct., 1861.

deg. South; and in two principal parts of this coast line, valuable coal-seams occupy the cliffs washed by the ocean, about Newcastle and the North of Illawarra. The position of the former is very advantageous for all the purposes of commerce; the latter has some disadvantages, owing to the difficulty of approach to the cliffs from seaward.

As in Newcastle-upon-Tyne, so also at Australian Newcastle, vessels can receive coal immediately from the mines at the mouth of the Hunter river, which by structures erected on a grand scale has been turned into an accessible and safe harbour. The coal-fields lie close by the sea-shore, some beds cropping out even upon the steep coast-bluffs, so that they can be distinctly seen from the sea, on a voyage from Sydney to Newcastle. There are, also, in the vicinity of this town, already eleven known seams extending over an area of about 6 miles along the coast, and 20 miles into the interior, having a thickness of from 3 to 30 feet.* The analysis of this coal gives: carbon 74·13 to 78·0, hydrogen and oxygen 25·87, ash 5·0, water 1·6.†

* Hochstetter's "New Zealand," Eng. trans., p. 75.

† *Ibid*, p. 91.

At Ballambi Point, north of Wollongong, operations for the shipment of coal, brought by a tramway from the seams situated in the Illawarra escarpment, have been some time carried on by Mr. Hale, the spirited proprietor of these mines, who has within the last few years entered on this important undertaking. Steps are also in progress for the commencement of a breakwater harbour at that Point, where the mineral treasures of vast extent, from no less than twelve seams, will be available for transport; and at Wollongong a new basin is being excavated.

"As some of these seams are traceable for many miles both northward and southward, the Illawarra will ere long supply abundance of fuel well calculated for the purposes of navigation.

"Passing to the coast north of the Hawkesbury, we find another series of seams extending from the Tuggerah Beach Lake to the left bank of the Hunter; the cliffs about Newcastle presenting an escarpment, varying up to 300 feet, in which seams of coal, that are worked inland, present themselves. Other seams occur in the Western Flats, and have been worked to various depths down to 400 feet below the sea. Within the last two or three years numerous fresh open-

ings have been made, and some rich seams, fully equal in thickness to the nine feet Upper Illawarra seam, have been discovered.

"Passing to the westward, the whole valleys of the Hunter and the Goulburn offer occasional occurrences of valuable Carboniferous deposits; as at Stony Creek, near Maitland, at Anvil Creek, and other localities, five seams occur at an enormous depth below the Newcastle beds. The following localities indicate some of the places where coal has long been known; viz.—Four Mile Creek, Hexham, base of the Myall Range, Wollombi, Morpeth, Maitland, Wallis Creek, Anvil Creek, Purrendurra, Glendon Brook, Tolga Creek on the Paterson, Leamington, Wollon, Jerry's Plains, Sadleir's Creek, Foy Brook, Falbrook, Ravensworth, Maid-Water Creek, Muswell Creek, Edenglassie, Piercefield, north of Bengala, at Gill's Cliff and Coyeo on the Page, near Murrurundi and Harbenvale, Kingdon Ponds, Mount Wingan, near Scone, and at the junction of the Hunter and Goulburn, as well as higher up on the latter river, near Gummum. Coal-beds also occur on the Talbragar and Cudgegong rivers.

"South-east of these localities, coal appears at the foot of Mount York, and at Bowenfells, near

Hassan's Walls; on the rivers Coxe and Wollondilly, on the Nattai, at Barragorang, on Black Bob's Creek, to the west of the Southern Hanging rock, at Balangola Creek, west of Arthursleigh, in the deep gullies about Bundanoon, Meryla, and the Kangaroo Ground. Below the plateaux, on which the seams crop out on the face of the Illawarra escarpment, above Jamberoo and Mullet Creek, and below Mounts Kembla and Keera, seams, to the number of twelve, occupy patches of cliff along the coast from near Waniora Point to a great fault ten or twelve miles northward; northwards of which, at Gara, the beds of shale connected with the coal rise at an angle of from two to four degrees from beneath the Hawkesbury rocks, which thence to the north of Brisbane Water occupy the coast. This dip seems general in the Illawarra, and also occurs on the Hunter. But it varies up to 16° on that river, and north of the Karuah to 50°, and in places to 90°.

"Passing on thus to the country about Port Stephens, between the Karuah and the Manning, we find a region of coal full twenty-five miles in extent, in which are no less than eighteen seams; of which one, measured by the writer, was thirty feet thick.

"This region has since been surveyed by M. Odernheimer of Nassau, for the Australian Agricultural Company, in whose estate this field occurs.

"Coal occurs in patches in other parts of New South Wales, and has been occasionally worked to the north of the Mittagong Range in the steep face of cliffs above the Nattai Creeks, near the Fitzroy Iron Works.

"Respecting the position of the coal in some of the localities, it may be observed, that the strike and joints of the rocks lead to the conclusion that the coast line merely intersects obliquely the general area or basin, which has thus its minor axis along the Hawkesbury; the Newcastle seams finding their prolongation about the Werriberri Creek on the Warragamba River, and the Bullai seams having had their northern prolongation many miles in advance of Newcastle, in a tract destroyed by, or below, the sea: all the evidence collected by observation leading to the inference that this Eastern coal-field is only a portion of a once much larger area, distinctive portions of which are occasionally thrown up by the sea on the beach rocks and sands. This is true, especially, of the Illawarra, where at Towrudgi Point, north of Wollongong, fossil wood

and trees exist near low-water mark, imbedded in natural position in the rocks; and at Ballambi, where similar trees are entangled, two seams of coal making their appearance also just behind the beach, and at and below the sea-level; and after gales, the beach at Wollongong is strewn with fragments of these and other Carboniferous spoils. Similar fossilized wood occurs at Newcastle, and in the Palæozoic beds of Black Head, south of Kiama, and of Stony Creek near Maitland.

"Judging from the enormous development of the Hawkesbury rocks on the Western slopes of the Cordillera, where they occur in patches at very great elevations on the summits of the older formations, or on the plains from the Western end of the Liverpool Range to the parallel of 26 degrees south, it may be fairly concluded that there is no present possibility of calculating the actual amount of available coal on that side of the Colony. Seams of coal are known, however, to occur in this area, on the Castlereagh; near the Nudawar Ranges, and on Reedy Creek, near Warialda, whence the writer procured cannel coal.

"A considerable portion of the counties of Clarence, Richmond, and Rous is occupied by

a similar formation, and workable coal exists therein both on the Richmond and Clarence Rivers."*

Queensland.—"The districts of Darling Downs and Moreton Bay are now constituted parts of the new Colony of Queensland, and coal-seams exist on the Bremer and Brisbane Rivers, and along the shores of the Bay, as on the coast, and on Mount Keera. Here the coal-seams are accessible by adits, and on the Brisbane the steamers can load by lying literally at the mouth of the mines, as is the case at Lake Macquarie. This phenomenon is characteristic of the coal of New South Wales. It is due to three principal conditions :—1. The generally nearly horizontal planes of some of the seams; 2. The elevation of the coal-country above the sea-level; and, 3. The persistent nature of the joints which traverse these elevated beds, at right angles to the planes of bedding, thus occasioning continual escarpments, in which the out-cropping seams appear on the faces of cliffs, or in more or less accessible ravines."

"To the northward of the Condamine, the Carboniferous formation extends over vast regions,

* The examination of this district is being vigorously carried on by Mr. J. Mackenzie, F.G.S., the Colonial Geologist.

in which coal undoubtedly exists. The writer has reported (Report X., Oct. 1853) the formation on the Condamine as occupying probably 20,000 square miles. He calculates also, from such data as are available, that on the M'Kenzie it occupies an extent of 40,000 square miles; and on the Robinson, 20,000 square miles. The country between the Condamine and the parallel of 32 degrees, occupied by similar beds, cannot be less than 15,000 square miles. And if we take into account the facts stated by Sir T. L. Mitchell, in his history of the explorations of the far interior, and the existence of the same Carboniferous formations, not only in various parts of the littoral districts of Victoria, but as far as the Grampian Mountains, westward of the 143rd meridian, it becomes manifest that there is no country on the globe, America excepted, occupied to so large an extent by these formations as Australia; and, with trifling exceptions, nearly all the enormous areas occupied by these Carboniferous beds belong to New South Wales and Queensland."*

Tasmania.—"This district abounds, also, in coal-beds, some considered the equivalents in

* Mr. R. L. Jack, F.G.S., is now engaged as Colonial Government Geologist in the exploration of this district.

age and position of the Illawarra and Newcastle seams of New South Wales; others, the equivalents of the *lower* coal-seams of Stony Creek near Maitland, occurring in the midst of a Palæozoic Fauna. The author's opinion of these Tasmanian coal-fields, as formed from personal inspection, has been confirmed by Mr. Gould, the Geological Surveyor of that Island, in his recent Reports to the Tasmanian Government."

"That gentleman has also discovered evidence to prove that the 'combustible schists' or 'Dysodile' of the Mersey River, on the North Coast of Tasmania, contain zoological fossils of Palæozoic age. In New South Wales, beds of a similar kind exist, of which specimens are exhibited from the higher northern slopes of the Liverpool Range, and from the base of Mount York in the County of Westmoreland. Examination shows that they are charged with *resin* (probably not unlike that so abundant in the New Zealand coal); and, therefore, they may perhaps be valuable as a source for the manufacture of mineral oil. The specific gravity of some of this substance the author has found to be 1·204. In appearance it is like lignite passing to cannel. It ignites readily, and burns with a prevailing odour. It is highly conchoidal

in fracture; and lies in masses from 6 to 12 ins. thick. A somewhat similar substance occurs in the Island of Cuba, and is there called *Chapapote.* But the New South Wales mineral is not so bituminous, and the specific gravity is less."

There are workings at Tasman's Peninsula, Port Seymour, New Town, and the Don. The coal is both anthracite and bituminous.*

Coal-fields of New Zealand.

This wondrously rich and varied group of islands seems to abound in all the mineral products of nature, not excepting coal. It is true that, for the present, gold almost absorbs the interest of its inhabitants, but this is only for a time; and as the grains and nuggets of this precious metal are washed out of the alluvial gravels, and gradually diminish in abundance, so the beds of coal will crop up, and assert their paramount importance as a source of prosperity and wealth to the inhabitants.

For a series of years, the carbonaceous deposits of New Zealand have attracted the attention of naturalists who have visited this country.†

* "Hints to Emigrants to Tasmania," by Mr. H. M. Hull (1871).

† One of the first observers on the geology and palæontology

Mr. C. Forbes, surgeon on board H. M. Ship *Acheron*, sent a very interesting account of the coal-seams of a large extent of coast, and of the experiments made on their qualities and composition, which he published in the Journal of the Geological Society of London, vol. xi., 1855.

In 1859, Dr. F. von Hochstetter, accompanied by his friend and travelling companion, Dr. J. von Haast, were appointed by the Government to commence explorations in the provinces of Auckland and Nelson; and this latter geologist, after having finished, in 1860, some important observations in the western districts of Nelson, was appointed Geologist by the Provincial Government of Canterbury. The labours of these enterprising naturalists have thrown much light on the coal-resources of large portions of the Island. Finally, in 1861, Dr. James Hector was appointed Geologist to Otago, and he has since (in 1866) published an able Report on the coal-deposits of the country, in which he divides the Carbonaceous deposits into two classes, the hydrous and anhydrous; the former being similar to the brown-coals of Europe, the latter being

of the island was Mr. Walter Mantell, son of Dr. Mantell, author of the "Metals of Creation," who sent home through his father communications on the geology of parts of the country to the Geol. Soc. London, 1848.

referable to the Mesozoic epoch, and more closely resembling "stone-coal."

The results of Dr. Hochstetter's explorations, and those of his companion during their joint survey, are given to the world in a noble work in which the physical history and structure of the Islands are graphically pourtrayed, together with their natural history.*

Character and Geological Age of the Coal-deposits.—The coal-seams of New Zealand are distributed over portions of both the North and South Islands; they occur in the form of *lignite*, a mineral fuel of inferior quality, and also of *brown-coal*, sometimes in thick beds, and of a quality not inferior to that of the best kinds of the German brown-coal, which is only inferior to English Carboniferous coal. This latter is considered to be of Mesozoic age, probably Jurassic. It is uncertain whether there is any "stone-coal" of Palæozoic age in this country.

North Island.—Deposits of brown-coal occur in the Drury and Hunna districts, 20 miles south of the city of Auckland. The vicinity of the capital, and of the Waitemata and Manukau

* "New Zealand, its Physical Geography," etc. (1863), Stuttgart, translated by E. Sauter (1867).

Harbours, with which communication has been established (1862), renders this coal-field very important. The merit of its discovery, in 1858, belongs to the Rev. Mr. Purchas. There is, *at least*, one bed of brown-coal, six feet in thickness, associated with remains of dicotyledonous plants, which leads Dr. Hochstetter to infer its Tertiary age.

Another tract with brown-coal lies on the banks of the Waikato, but is at present unopened; one seam here has a thickness of 15 feet, and lies in a horizontal position along the base of the slate mountain Taupiri.

A coal-formation of probably Mesozoic age has recently been detected in the northern districts of Auckland, in the vicinity of Wangaroa Harbour. A large portion of the isolated hills at the North Cape is composed of this formation. According to Dr. Hector, the bituminous coal of Kawa-Kawa is of a quality superior to that of any other coals of the province.

Besides the above, there are to be found on the shores of Manukau Harbour, in the flats of Drury, Papakura, and Waikato, etc., deposits of *lignite*, which must not be mistaken for brown-coal.

South Island.—Of greater variety and extent

appear to be the coal-deposits of South Island, which seem destined to be capable of supplying a large portion of the fuel for the steam navigation of the Pacific Ocean. At a distance of four miles S. of the city of Nelson, a colliery has been opened in several seams of *brown-coal*, from 3 to 6 feet in thickness. Still farther south near Mount Arthur, and on the Wangapeka and Batten rivers, coal-seams have also been discovered.

The coal of Massacre, or Coal Bay, W. of Nelson, has been opened to a small extent. The seams lie at the level of high-water mark and below it, in a nearly horizontal position; and the coal has been used for steam navigation purposes.*

The extent of the coal-field near Motupipi is considerable; the coal-seams having been found at various places up the Takaka river for a considerable distance. They belong to the *brown-coal* series, and are imbedded in bituminous shales, sandstones, conglomerates and limestones, such as are frequently met with in Germany.†

The coal-deposits of Pakawau, in Golden Bay,

* On board the *Nelson* in 1854-5.

† Hochstetter, "New Zealand," p. 84.

appear to be of a different, and more ancient, date than those just described. The coal is of a firmer consistency and gaseous, but has not yet been found of sufficient thickness to induce extensive mining operations. The extent and resources of this coal-field are as yet little known.

Dr. Haast has made important discoveries of coal in the provinces of Nelson and Canterbury; especially on the Buller (or Kawatiri), and Grey (or Mawhera) rivers.* On the flanks of the Papahaua range, he discovered a fine bed of coal 8 feet thick at a height of 1,500 feet above the sea, and extending over an estimated area of 8 miles in width by 15 in length.

Of still greater importance are the discoveries on the Grey River entering the sea on the west coast. Here two workable seams are known in the Waipara (Cretaceo-Tertiary) formation, of which the lower is 16 feet; they are interbedded with micaceous sandstones and shales, which have yielded dicotyledonous leaves, and remains of Cycads, with *Zamites*, *Pecopteris*, and *Equise-*

* An analysis of the coal from Nelson at the mouth of the Grey River, by Dr. Percy, gives the following results:—Carbon 79·00, hydrogen 5·35, oxygen 7·71, ash 3·50, water 1·05 per cent., coke 64·32. It is a caking coal, and probably a good gas . ("Metallurgy," p. 100.)

tum. The coal resembles that of Newcastle in Australia, and is little inferior to English coal.*

The coal-deposits of Pakawau, the Buller, and Grey rivers are considered by Dr. Hochstetter to be of Mesozoic age, and probably the representatives in time of the Yorkshire Oolitic coal in England.

The analysis of the Pakawau coal gives the following results,—carbon 66·72, hydrogen and oxygen 23·18, ash 8·4, water 1·7.†

On the eastern side of the South Island, carbonaceous deposits have also for some years past been known to occur. The Kowhai coal-field, about 30 miles from Christchurch in Canterbury, contains several workable seams, in which a coal-mine has been at work since 1857. Deposits of brown-coal are also known to underlie the great Canterbury plains, and crop out in the valleys of the Selwyn and several other rivers, and in the Malvern, Big Ben, and Somers Hills.

* See Dr. Hector's Report (1866). The grey coal is described as compact, black, of a dull lustre, with slaty cleavage. The coal puffs up slightly when heated, and gives 68·37 per cent. of coke. A concise account of the coal-seams of the Provinces of Canterbury and Westland will be found in the work of Dr. von Haast in the geology of those provinces, p. 450 (Christchurch, 1879).

† Herr *v.* Hauer, quoted in Hochstetter's "New Zealand," p. 91.

The province of Otago also contains deposits of *brown-coal* on the southern coast, north from the Molyneux river, where they extend over an area of at least 45 square miles, and in which there are several seams of good coal varying from 6 to 20 feet in thickness. Two large mines have been opened in this field, and the coal is used chiefly for the purposes of steam navigation. The same formation occurs in the Green Island and Saddle Hill Basin, where two seams of a thickness of 7 and 9 feet have been worked.

A third tract of the brown-coal formation occurs along the eastern sea-board of Otago, extending inland to the base of the Kakanui Mountains; and other small patches occur at intervals in the interior portions of the province. The same formation is also known to occur in South Island in several places.

With resources in mineral fuel so great, together with those supplies of the useful or precious metals which she is known to possess, New Zealand seems to have all the materials for the foundation of commercial and manufacturing prosperity. And when added to this we take into account the extraordinary fertility of her soil, and the sub-tropical character of her climate, her ample supplies of water, ever flowing down

from groups of hills in the interior, or ranges of snow-clad mountains, appropriately called "The Southern Alps," and recollect that all these have been granted by an overruling Providence to the sons of Albion, bringing with them the institutions, the traditions, and the enterprising spirit of the mother country, may we not predict for the "Britain of the South" a great and glorious future?

AFRICA.

As compared with the other continents Northern Africa, as far as it is at present known, appears to be remarkably destitute of fossil fuel; nevertheless, the researches of Livingstone have brought to light coal-deposits on the banks of the Zambesi, described by the late Mr. Thornton, geologist to the exploratory expedition. Dr. Livingstone has rightly estimated the beneficial effect upon the future navigation of this great river, likely to be exerted by the existence of these "stones that burn," the term by which the natives designate this mineral.*

In South Africa considerable tracts of coal

* In Livingstone's second journey, coal was discovered at Tette, on the Zambesi, one seam being 25 feet in thickness.—"Expedition to the Zambesi and its Tributaries," p. 52, 1865.

and iron-bearing strata have recently been explored, both in the Cape Colony, Natal, the Orange River Free State, and in the Transvaal. Mr. E. J. Dunn has drawn up a Report on the occurrence of two sets of coal-bearing beds on the N.E. margin of the Stormberg (near Bushman's Hoek), north of Queenstown,—one of probably old "Carboniferous" age, and the other belonging to the upper part ("Stormberg") of the great Karoo Series,—as indicated in the Quart. Journ. Geol. Soc., vol. xxvii. p. 52; and, though the Report above noticed does not support that view, something like it is now proved to be the case at about 150 miles W. by S. from Queenstown. Mr. Dunn has found an exposure (*inlier*) of some underlying coal-bearing (anthracitic) strata, distinct from the surrounding and unconformable Karoo Beds, at Buffel's Kloof, on a spur of the Camdeboo Mountains, between Graaf-Reinet and Beaufort West; and again at Brandewyn's Gat, by the Leeuwe River, on a spur of the Nieuwveldt, 36 miles N.W. of Beaufort West, and 100 miles W. of Buffel's Kloof. By making careful sections of the strata between Beaufort and Graaf-Reinet, and by examining the sections opened out by the new railway running S.W. from Beaufort across the Dwyka,

Bloed, and Buffel's Rivers and the Wittenberg range, Mr. Dunn has fully explained the relation of the horizontal Karoo series as unconformable to the underlying tilted, folded, and broken "Ecca Beds," with their inclosed and conformable "Dwyka Conglomerate."

At Buffel's Kloof the diggings and shaft clearly show that one or more rather thick seams of coal (anthracite) in the underlying inclined beds have been broken and crushed by a fault, and even forced up into the higher fissures contained in the overlying horizontal Karoo beds, which do not hereabouts contain coal. The shales in which the coal is bedded contain "Glossopteris and Calamites!"*

Mr. Dunn describes the constituent strata of the Stormbergen as—at top—1. Volcanic: lavas, tuff, agglomerate, ash-beds, and amygdaloids, with volcanic bombs in sandstone, about 400 feet. 2. Cave-sandstone: buff-coloured, pinkish, greenish, white and grey, fine-grained, thick-bedded sandstone, about 150 feet; with fragments of Sauroid bones. 3. Red beds: friable, red and purple, arenaceous shale, and

* "Report on the Camdeboo and Nieuwveldt coal, Cape of Good Hope." (1879). See notice in Geol. Mag., Nov. and Dec., 1879, by Prof. T. R. Jones.

sandstone, about 600 feet; with Sauroid bones; and some fossil wood in the lower beds. 4. Coal-measures: grey and light-coloured sandstones, generally felspathic, alternating with shales, in which occur coal-seams, and conglomerates, about 1,000 feet; carbonized plant-remains abundant in the sandstones, ferns in the shales; fossil wood abundant; fossil bones very rare. Doleritic dykes penetrate the whole series. The " Stormberg " strata, he says, continue throughout the Drackensberg range, and the series is as strongly marked near Harrismith as in the Stormbergen. They lie conformably on red, greenish, and grey shales, with grey sandstones, rich with Dicynodont and other reptilian remains. From the position the coal-measures occupy, it is clear that coal-outcrops will be found right round the base of the Drackensberg, and equally clear that the seams are thicker and the quality better the further they occur to N.E. from the Stormberg. In Natal, at Biggarsberg, is a seam of coal, eight feet thick, of better quality than the Stormberg coal. In the Transvaal equally thick seams of superior coal are known in the High Veldt. A few outcrops are known in the Free State. Properly directed explorations would result in tracing the

outcrops through Kaffirland, Natal, the Transvaal, and Free State. In the higher parts of Basutoland, and, in fact, along the higher portions of the Drackensberg chain and its spurs, no coal will be found; the seams do not occur at such altitudes.*

From the Free State, Mr. Stowe, F.G.S., reports that the following useful materials occur:—

1. Nodular limestone, such as used in other countries as cement-stone, scattered over various parts of the State.

2. Great beds of old crystalline limestones (siliceo-calcareous rocks).

3. An immense area of country filled with porphyritic rocks, which would vie with granite for durability and beauty.

4. An abundant supply of magnetic and other rich iron-ores, within a convenient distance of the necessary fuel for smelting.

5. A great coal-bed.

In a former report he stated that, judging from the excavations made in the Sand River district, the coal underlying that portion of the country would, at a low estimate, amount to some 145,800,000 tons. We can now safely

* "Report on the Stormberg Coal-field" (1878).

state that in the new coal-field, since discovered in the Vaal River valley, the minimum quantity would be some 350,000,000 tons; making a total, in the two coal-beds, of 495,800,000 tons.

From calculations based on those used in England, Mr. Stow finds that the Free State coal-supply would be sufficient to allow of a yearly consumption of more than 6,000,000 tons for a period of 1,200 years!

It is not improbable that, as outcrops of coal in this portion of South Africa show themselves in the Free State, along the Vaal Valley, and also in the Transvaal, west of the Drackensberg, associated with the rocks dipping eastward, and as they again appear in the Utrecht Division of the same province, as well as at Biggarsberg (Newcastle) in Natal, to the east of the same great range, these are all parts of the same great coal-field; the Drackensberg mountains occupying their synclinal trough. If, after proper investigation, such should prove to be the case, the supply of South-African coal will be enormous, throwing the figures above quoted, vast as they appear, completely in the shade.*

* "Friend of the Free State," Aug. 7, 1879; quoted in Geol. Mag., Nov. 1879.

CHAPTER IV.

NORTH AMERICA.

British Possessions.

THE States of America not appertaining to the British Crown have retained possession of by far the greater portion of the coal-producing region of the North American continent. In Canada proper, there exists not a vestige of the coal-formation: and the coal-fields within the boundaries of the British Empire are confined to its outlying north-eastern districts of Newfoundland, New Brunswick, and Nova Scotia, and the borders of the Rocky Mountains. These we now proceed to describe.

NEWFOUNDLAND.

From the survey of Mr. Jukes, it appears that there are two small, and, as far as known, not highly productive, coal-fields in Newfoundland; one extending along the eastern shore of St.

George's Bay, some distance inland, and the other from Grand Pond to White Bay.*

The formation is similar to that of Nova Scotia, consisting of two members which pass into each other. The lower member consists of red sandstone, red and green marls, with gypsum; the upper, of dark shales, fireclays, sandstones, conglomerate and coal. This last has been found in several places, marked on Mr. Jukes' map; the thickest bed being about three feet.

NEW BRUNSWICK AND NOVA SCOTIA.

The geological structure and mineral resources of this region have been very lucidly described by Dr. Dawson.† From the excellent geological map which accompanies his work, it would appear that nearly one-half of these territories are composed of Carboniferous rocks; but of this less than a third contains productive Coal-measures.

The following is the general succession of the Carboniferous series:—

	Thickness.
1. *Upper Coal-series.*—Grey and red sandstones and shales, conglomerates, and a few thin beds of limestone and coal of no economic value . .	3,000 feet.

* "Geology of Newfoundland."

† "Acadian Geology."

	Thickness.
2. *Middle Coal-series.*—Grey and dark sandstone, and shales, etc., with valuable beds of coal and ironstone; beds of bituminous limestone, and numerous underclays with *Stigmaria* . .	4,000 ,,
3. *Lower Carboniferous or Gypsiferous series.*—Reddish and grey sandstones and shales, overlying conglomerates; thick beds of limestone with marine shells, and of gypsum; more than	6,000 ,,

Fossil Remains.

The fossils of the upper series are composed principally of plants, as *Calamites*, *Ferns*, and Coniferous wood.

In the middle series, representing the middle Coal-measures of England, remains of both the animal and vegetable kingdoms appear to be remarkably abundant, and are classed by Dr. Dawson as follows :—

Reptiles.—*Dendrerpeton Acadianum*, discovered by the author and Sir C. Lyell, within the upright trunk of a Sigillaria. *Baphetes planiceps*, a large batrachian allied to Labyrinthodon; besides one or more species indicated by their tracks.

Fishes.—*Palæoniscus*, *Holoptychius*, *Megalichthys*, and several other undetermined genera.

Articulata.—*Cypris* or *Cytherina*, several species. *Spirorbis*, either embedded or attached to plants.

Mollusca.—*Pupa vetusta*, the first example of a land shell ever found in the Carboniferous rocks. *Modiola*, *Anthracosia* (Unio), of two or more species.

A large number of plants of European genera, and many of European species.

The Lower Carboniferous series, representing all the strata of England, from the Millstone Grit downwards, contains a reptile, discovered by Sir William Logan; fishes of the genera *Holoptychius* and *Palæoniscus.* Of Annelides, *Spirorbis;* of Crustaceans, a *Trilobite* or *Limulus;* besides a large series of Mollusca, of the genera *Nautilus*, *Orthoceras*, *Conularia*, *Euomphalus*, *Natica*, *Terebratula*, *Spirifer*, *Productus*, *Cardiomorpha*, *Pecten*, *Avicula*, *Modiola*, *Isocardia*, *Cypricardia:* of Polyzoa, *Fenestrella*, *etc.*, Crinoids, etc.; and a few plants.

CUMBERLAND COAL-FIELD.

This is by far the largest Carboniferous tract, covering an area, according to Professor Rogers, of 6,889 square miles.* It extends along the whole line of coast, and as far inland as the base of a range of mountains which stretch along the northern coast of the Bay of Fundy. Its southern limits are the Cobequid Hills. Unfortunately, the surveys of this great coal-field have not tended to raise our expectations of its economic importance, as the greater portion of it appears to be composed of the Lower and Upper Carboni-

* "Geol. of Pennsylvania," vol. ii.

ferous series, both of which are destitute of valuable coal-beds.

If economically unimportant, it is far otherwise in a scientific point of view, as, along the coast of the Bay of Fundy, at South Joggins, it displays the finest natural section of the Coal-formation in the world. The whole series of this district attains a thickness of 14,570 feet, with 76 seams of coal. Of these, 4,515 feet are brought to light in the coast-section. The beds rise along the face of the cliffs, clean and fresh, to a height of 150 feet, at an angle of 19°; so that, in proceeding along the coast from north to south, for a distance of about ten miles, we arrive at constantly newer beds, which at low tide may be traced out from the base of the cliff for a distance of 200 yards. Sir C. Lyell counted 19 seams of coal, and at least 10 forests of upright stems of Sigillaria, the longest of which was 25 feet, with a diameter of 4 feet where broken off; they were found invariably based on the upper surfaces of the beds of coal.

In the Cumberland coal-field, the principal coal is the "Joggins Main Seam," consisting of two beds, 3½ and 1½ feet thick. There are also six or seven workable seams at Springhill with a total thickness of 42 feet

coal,* besides several places in New Brunswick, especially a remarkable pitch-like vein called the "Albert Mine," on the Petitcodiac River.

COAL-FIELD OF COLCHESTER AND HANTS.

This district is separated from that of Cumberland by the Cobequid chain of hills, and has an area of about 200 square miles. It is principally valuable for its limestone and gypsum. The coal-seams appear to be all under 18 inches in thickness.

COAL-FIELD OF PICTOU.

This coal-field has an area of about 350 square miles, and is remarkable for containing two very thick beds of coal, the upper 37 feet, and accompanied by three other workable beds having an aggregate thickness of nearly as much more, separated by 157 feet of strata. These seams have partings of inferior coal and ironstone at intervals. The upper bed has been largely worked at the Albion mines; and though there of good quality, has been proved to deteriorate at a short distance both to the north and south of that locality. Recently, however, according to

* Mem. Geol. Survey of Canada. Rep. by A. R. C. Selwyn F.R.S., for 1870-71, p. 6.

the statement of Dr. Dawson, an extension of these great beds of coal has been proved over five new properties, which must contain a workable quantity of 150 millions of tons of good coal; and there is reason for believing that the area is still considerably greater.*

COAL-FIELDS OF RICHMOND AND CAPE BRETON.

The combined areas of these fields may be estimated at 350 square miles. Several workable seams of coal have already been discovered, besides valuable deposits of limestone and gypsum. For our knowledge of the Sydney coal-field we are particularly indebted to Mr. R. Brown, who gives the following synopsis :—The productive measures cover an area of 250 square miles, with a thickness of about 10,000 feet of strata.† Of several very fine natural sections exposed to view along the coast, the most interesting is that to the north-west of Sydney Harbour, extending a distance of 5,000 yards, and exhibiting a vertical thickness of 1,860 feet of strata. Of these, 34 are coal-seams, com-

* "Geol. Mag.," February, 1867.

† Journ. Geol. Soc., London, vols. ii. and vi. See also Geological Map and Report on the Sydney Coal-field, in Report of Progress of the Geol. Surv. of Canada, for 1875-76, by A. R. C. Selwyn (1877).

bining to produce 37 feet of coal. Four only are workable. The following is the general section of these coals:—

	Feet.	In.
Cranberry Head Top Seam	8	8
Strata	280	0
Lloyd's Cove Seam	5	0
Strata	730	0
Main Seam	6	9
Strata	450	0
Indian Cove Seam	4	8

Valuable coal-seams occur also at Lingan and Bridgeport; one of which, 9 feet in thickness, yields a fine coke, and is esteemed as a gas-coal. Limestone and gypsum also abound; and, on the whole, the mineral resources of Cape Breton county appear very promising.*

In 1870, the quantity of coal raised in the district was 333,803 tons.

Emigrants and settlers would do well to make themselves acquainted with the mineral resources of the districts in which they propose to settle; as they may thus procure a tract of land which may prove, from its mineral wealth, of benefit to themselves and their descendants.

* Mr. Brown has recently published an important treatise, entitled "The Coal-fields and Coal-trade of Cape Breton," with maps and illustrations (London, 1871), giving very complete information regarding the subject on which it treats, to which the reader is referred for fuller information.

CHAPTER V.

STATES OF NORTH AMERICA.

THE great hydrographical basin of the Mississippi and its tributaries is underlaid throughout the greater part of its area by productive Coal-measures, with enough coal to supply the whole of that vast continent, were it is as populous and as industrious as Britain, for a decade of centuries. This great Carboniferous formation spread originally in one continuous sheet over the whole of Central America, probably from the flanks of the Rocky Mountains to the shores of the North Atlantic, and from the Gulf of Mexico to Newfoundland; and though we are unable strictly to define the original margin and limits of this great coal-generating tract, yet there is reason to believe, as has been pointed out by Sir C. Lyell, that land existed at that period where now rolls the Atlantic; and that the British Islands were connected with America by a chain of islands, or a tract of land, over which

the plants of the Carboniferous period migrated and spread themselves in dense forests. Such an hypothesis seems the most satisfactory explanation of the remarkable fact, that the Carboniferous vegetation of America is identical, at least generically, with that of Europe; which could not have been the case under any of the received theories of the distribution of plants and animals, if these regions had been separated by wide barriers of ocean.

Moreover, in tracing the Carboniferous strata, from Texas and Missouri on the south-west to the Alleghany Mountains and Nova Scotia on the east and north, we find a progressive thickening of the sedimentary materials, such as sandstones and shales, which become both more abundant, and of coarser texture, as we approach the seaboard of the Eastern States. This points to the position of the old land, from which these materials were derived, as having lain somewhere in the North Atlantic; and, combined with the evidence derived from the vegetation, becomes almost demonstrative of the presence of land where now is sea.

The great tract of Coal-measures, which was, without doubt, originally connected throughout, has now become distributed into several coal-fields

more or less distinct. The late Professor H. P. Rogers enumerated five of such coal-fields, and estimated their united area at 196,863 square miles,* but a more recent account by Professor C. A. Hitchcock makes the number of the coal-fields and the combined area considerably larger; as follows: †—

1. New England Basin; anthracite coal, with a maximum of 23 feet of coal, area	750 sq. miles.
2. Pennsylvania Anthracite Basin; max. of coal 207 feet ‡ . .	434 ,,
3. Appalachian Basin. Coal bituminous. This coal-basin ranges through the States of Pennsylvania, Maryland, West Virginia, Ohio, East Kentucky, Tennessee, Georgia, and Alabama. In West Virginia, the thickness of coal amounts to 51 feet . . .	63,475 ,,
4. Michigan Basin, with 11 feet (max.) of coal	6,700 ,,

* "Geol. of Pennsylvania."

Geol. Magazine, vol. x., p. 99. The reader will find in Macfarlane's "Coal Regions of America," 1873, a large amount of information extracted from the States Surveys, thrown into a condensed form. There is also a small but very beautiful map of the American coal-fields by M. Jules Marcou, in Peterman's "Mittheilungen," vol. vi. (1855).

‡ Mr. P. W. Sheafer estimates the area at 470 square miles, and the thickness of coal at an average of 107 feet.

5. Illinois Basin, ranging through Illinois, Indianà, and Western Kentucky, with 35 feet (max.) of coal .	51,700 sq. miles.
6. Missouri Basin, extending from Iowa to Texas, including parts of Nebraska, Missouri, Arkansas and Indian territory. Area more than	100,000 „
7. Texas Basin, a branch of the preceding	6,000 „
Total area more than	229,059 „

Over the central and western districts, the strata lie regularly, and only slightly removed from the horizontal position; but on proceeding eastwards, and approaching the chain of the Alleghanies, they become bent; and ultimately folded and crumpled along lines parallel to the axis of the mountains. Corresponding with this folding of the beds, the coals lose their bituminous properties, and along the western flanks of the mountains occur only as anthracite. The close connection between the crumpling of the coal-seams, and the loss of the volatile constituents of the coal itself, is strongly marked; for in proportion as we recede from the axis of disturbance, the coal-seams become more bituminous.

The Alleghany Hills consist of a succession of parallel ridges, divided by narrow and deep

valleys, corresponding to the folding of the strata. The axis is nearly parallel with the coast of the Atlantic, and reaches at Black Mountain an elevation of 6,476 feet. The geological structure of this remarkable range leads to the conclusion that it has been formed by the exertion of lateral pressure, acting along the Atlantic side, and forcing the strata towards the west, with a power to which geology affords few parallels. In consequence of the structure of the beds, and the subsequent partial denudation, these mountains contain several small trough-shaped coal-fields, in which the coal has become metamorphosed, and assumes a columnar structure, the axes of the columns being perpendicular to the planes of bedding. There are also springs of pitch and petroleum, of great value; and others of brine, containing 10 per cent. of common salt (chloride of sodium), and small quantities of iodine and bromine. Free carburetted hydrogen also bursts forth at the fountains of the country.*

The thickness of some of the seams of coal is in keeping with the vastness of the coal-fields. In consequence of the thinning away of the sedi-

* Professor Rogers. (From a communication to the British Association, 1860.)

mentary materials westward, several seams are often brought into contact, and form one mass. Thus in the Bear Mountains there has been formed a seam of 40 feet in thickness, which is described by Sir C. Lyell. It is anthracite, and is quarried from the outcrop into the hill. Sir Charles considers that the thickness of the original mass of vegetable matter, before condensation of pressure, and the discharge of its various gases, may have been from 200 to 300 feet! *

The Coal-measures, as in England, rest upon a floor of Carboniferous Limestone, with, in some places, Millstone Grit intervening; the age of the coal-fields in both countries is therefore identical. The fossils of the Carboniferous Limestone are generically the same with those of Europe—such as *Spirifer*, *Orthis*, *Terebratula*, *Productus*, *Pentremites*, and *Retepora*.

The plants from the Coal-measures are *Lepidodendron elegans*, *Sigillaria Sillimani*, *Neuropteris cordata*, *N. Loshii*, *Pecopteris lonchitica*,

* Mr. P. W. Sheafer, in a paper read before the American Assoc. for the Advancement of Science (1879), states that owing to the thickness of the coal-seams in the Anthracite districts, the high angle at which they are inclined, and other causes, the loss in mining of coal is very large, not more than 66 per cent. being taken out of the mine.

Calamites Cistii, etc., of which all but the second occur in Europe.

*The Triassic Coal-field of Richmond, Virginia.**

Some miles east of Richmond a small coal-field of 26 miles from north to south, and 12 in its greatest diameter, occupies a depression in the granitic rocks of that part of the country.

The Richmond coal-field contains several beds of valuable coal, one of which is from 30 to 40 feet in thickness, highly bituminous, and equal to the best coal of Newcastle.

Other Coal-fields and Lignite Formations.

In Colorado and New Mexico, Dr. Hayden and his assistants of the Government Survey report the existence of enormous quantities of coal associated with iron-ore, especially along the base of the Raton hills and Placiere moun-

* This coal-field was supposed by Sir C. Lyell to be of Jurassic age; but M. J. Marcou, and Dr. O. Heer (on the evidence of the plant remains) refer the beds to the Triassic period, a view supported by Prof. T. R. Jones, from an examination of the fossil *Entomostraca* from this formation. The reader will find the subject ably handled by the last-named author, in the Monog. fos. estheriæ; Palæont. Soc., 1862, p. 84, *et seq.* The late Dr. Oldham considered the Richmond coal-field as probably of the same age as that of the coal-formation of India.

tains.* These are now known, I believe, under the general name of "the Laramie coal-fields," from the geological formation in which the coal is found, and which appears to lie on the borders of the Cretaceous and Tertiary groups.

The most important of these coal-fields extends across the boundary between Colorado and New Mexico, and is described by Professor J. J. Stevenson as occupying an area of about 2,200 square miles, and contains numerous coal-seams interstratified with sandstones and shales, containing *Halymenites*. The coals are liable to rapid changes in thickness and quality, and are laid open to view in some of the valleys and cañons which traverse the tablelands of that remarkable region.†

Similar beds of coal or lignite are described by Mr. Clarence King as occurring in the Laramie group along the Fortieth Parallel.‡ Deposits of coal are also found in Idaho and Wyoming, which have been opened up to some extent along the line of the Union Pacific Railway, and are described by Dr. F. V. Hayden and his assistants of the American Survey.§

* Report U. S. Survey, 1869.

† American Journ. Science and Art, vol. xviii., 1879.

‡ Report, p. 330, *et seq.* (1878).

§ Eleventh Annual Report, 1877.

Coal-fields of smaller extent and uncertain age occur, according to M. Marcou, at the sources of the Rio Colorado, in the Utah territory, and on the shores of the Pacific Ocean north of Cape Blanco.*

In Vancouver Island, and on the opposite coast of America, there are extensive deposits of Tertiary and Cretaceous age, bearing beds of lignite and coal, which are extensively worked for the supply of the steamers navigating between Victoria and the Frazer River.† Of this coal that obtained from Nanaimo is admitted to be the best.‡

Mr. Isbister describes extensive lignite deposits in the valley of the Mackenzie River, probably of the same geological age as those in Vancouver Island. These strata have been traced by Sir J. Richardson from the shores of the Arctic Sea, along the eastern base of the Rocky Mountains as far south as lat. 52°. The beds of lignite attain a thickness of 9 feet, and

* "Geologische Karte der Vereingten Staaten," in Peterman's "Mittheilungen," 1855.

† Mr Bauerman, Journ. Geol. Soc., vol. xvi., p. 201.

‡ For details see Mr. J. Richardson's Report addressed to Mr. A. Selwyn. Report Geol. Survey, Canada, 1871-2; also, Report of Progress, 1876, p. 160.

are well shown where the Bear Island River flows into the Mackenzie.

Dr. J. Hector, who accompanied Captain J. Palliser's expedition in 1857-60, has determined the Geological age of the lignites of North-western America and Vancouver Island to be Cretaceous, though others of inferior quality and of Tertiary age also exist.

The following is a section of the Lignite group obtained by Dr. Hector on the bank of the Saskatchewan River, near Fort Edmonton:*—

1. Superficial sand and gravel.
2. Grey sandy clay.
3. Lignite—1 foot thick.
4. Shale.
5. Lignite—2 feet.
6. Clay and sandstone.
7. Lignite, very pure, 3 feet.
8. Concretionary greensand.
9. Lignite, pure and compact, 6 feet thick, with a band of soap-clay, 6 inches thick.

This bottom bed of lignite was analysed by Mr. Tookey at the Laboratory in the Museum of Practical Geology, and was found to contain about 16 per cent. of ash. Very thick beds of

* For a very interesting account of the Coal-fields of the North Pacific Coast, see Mr. Robert Brown's communication to the Edin. Geol. Soc., 1868-9.

lignite have also been observed on the banks of the Red Deer River, a tributary of the Saskatchewan. On the importance to British commerce of the coal deposits in British territory on both sides of the Rocky Mountains, Dr. Hector lays just stress, showing that they offer a certain inducement towards a route to China and the East by Canada, the Saskatchewan, and British Columbia.

California.—According to the statement of Mr. Macfarlane, no true Carboniferous coal has ever been found in California, Oregon, or in any of the territories west of Kansas. The formations of the region bordering the Pacific are of newer age than the Carboniferous, and whatever fossil fuel occurs from Behring's Straits to those of Magellan, consists of lignite.* A fair description of this variety is found at Mount Diablo near San Francisco, Coos Bay in Oregon, Settle, on Puget Sound; Bellingham Bay in Washington Territory, and in Vancouver's Island. The mines at Mount Diablo are connected with the city by rail. Coal and lignite occur also on Jameson Land, Banks' Land, and Melville Island. In Albert Land, in lat. 78°, Sir E. Belcher found bituminous schists with coal, and apparently

* Coal-Regions of America, p. 561.

connected with these strata, limestones with *Productus* and *Spirifer*.

*Coal-fields of the North Pacific Coast.**

Mr. R. Brown, F.R.G.S., who has had extensive opportunities of investigation, states that these coal-fields, three in number, extend from the borders of Alaska to California, and belong respectively to the Tertiary, Secondary, and Palæozoic ages; the last being situated in Queen Charlotte's Islands, off the northern coast of British Columbia, yields anthracite. The Secondary beds are confined to the Island of Vancouver, and they may be a continuation of the Cretaceous strata of Missouri; while the Tertiary coal-fields extend from California northward through Oregon and Washington Territory, touching the southern end of Vancouver Island and British Columbia. The following analysis of the native and imported coals may prove interesting:—

* For a very interesting account of the coal-fields of the North Pacific Coast, the reader is referred to the communication of Mr. Robert Brown, laid before the Geological Society of Edinburgh, 1868-9.

strata, consisting of shales, sands, and carbonaceous clays, which contain these coal-seams, reach a total thickness of about 2,000 feet. They range across the island in parallel zones, and present interesting sections along the coast, very faithful details of which are presented by Mr. Wall. The asphalte is almost invariably disseminated in the newer Parian group, which contains the beds of lignite and a large amount of vegetable matter.

The same Tertiary formations, under the term "Newer Parian," have been traced by Mr. Wall on the neighbouring coast of the Continent, and are known to contain lignite and coal at Piaco on the Orinoco, and in the provinces of Barcelona and Coro. Mineral pitch is also found in these strata.*

It is proper to observe that these Tertiary lignites are inferior in economic value to the coal of the true Carboniferous formations of Europe and North America; and so long as these latter are shipped in sufficient quantity into the West Indian Islands, the fossil fuel of Trinidad is not likely to be largely worked.

* Mr. Wall, Journ. Geol. Soc., vol. xvi.

CHAPTER VI.

COAL-FIELDS OF SOUTH AMERICA.

Empire of Brazil.—The Province of Rio Grande do Sul, at the southern extremity of this great empire, is now known to be exceedingly rich in mineral fuel. According to the observations of Mr. N. Plant,* there are three distinct coal-basins contained within the limits of lat. 30° and 32° S., long. 51° and 54° W., which are separated from each other by rolling hills of granite and schist, with trachytic and basaltic rocks. The largest of these basins occupies the valleys of the Jaguarao and Candiota, and the strata, consisting of sandstone at the top, and shale, coal, and limestone below, dip southward at an angle of 10° to 15°.

The following section is exposed in the escarpment of the Sierra Partida, in this basin, as given by Mr. N. Plant; the beds in descending order:—

* Geol. Mag., No. 58 (April, 1869).

			Ft.	In.
No.	1.	Ferruginous sandstone	25	0
,,	2.	Shale (coaly)	9	0
,,	3.	Sandy shale	5	0
,,	4.	*Coal*	8	0
,,	5.	White shale with plants	5	0
,,	6.	*Coal*	11	0
,,	7.	Parting of blue clay	2	0
,,	8.	*Coal*	17	0
,,	9.	Shale with fossils	9	0
,,	10.	*Coal*	25	0
,,	11.	Shales with ironstone and ferns, resting on sandstone.		

The second basin lies in the valley of the São Sepe, one of the tributaries of the river Jacuahy, in about lat. 30° 20′, long. 53° 30.′ Two distinct beds of coal, one 7 feet, and the other 14 feet thick, appear in this locality, underlying sandstone, apparently the same as that which overlies the coal of the Candiota valley.

The third basin is near the town of São Jeronymo, on the banks of the Jacuahy, lat. 30°, long. 51° 30′. Here the coal has been for some time extensively worked by Mr. J. Johnson. The sections of the strata show deposits similar to those of Candiota. At a depth of 19 yards is a bed of bituminous coal 6 feet thick, below which are others interstratified with shales and ironstone.

Carboniferous deposits also occur in the province of Santa Catherina. About 45 miles N.W

of the seaport of Lagana, the basin is intersected by the river Tubarao and its tributaries. In this basin, five seams from 18 inches to 10 feet have been met with, underlying a sandstone formation.

Banda Oriental, or *Uruguay.*—The coal-bearing formation of Southern Brazil is continued into this Republic, and the succession of the beds is stated by Mr. Plant to be similar to that above described. Along the head waters of the Rio Negro beds of shale and coal are overlaid by a thick deposit of sandstone.*

Geological Age of the South Brazilian Coal-formation.—The plant-remains from the shales associated with the coal-seams of Candiota, were submitted to Mr. W. Carruthers, F.R.S., of the British Museum, who has been able to determine three species, and to recognise more vaguely a number of other forms, all of which belong to Palæozoic genera, while the species occur in the Coal-measures of Great Britain. The genera observed are *Flemingites*, (Carr.), *Odontopteris*, and *Næggerathia.*† It would appear from this, that the formation is of true Carboniferous age.

The existence of these deposits of mineral fuel

* Geol. Mag., April, 1869 (150).

† Geol. Mag., April, 1869, 151-6 (with plate).

is calculated to be a source of considerable wealth to a portion of the empire, whose enlightened ruler is ever ready to advance the interests of science, and to extend the social and commercial prosperity of his people.

Chili.—Tertiary strata, containing beds of "brown-coal," are found along the coast of Chili, forming several little detached basins, and resting on a basis of metamorphic schists and intrusive rocks.* The most important district is that lying between Conception and Valdivia, which contains the two largest collieries of the country, those of Coronel Puchoco and Lota; from which the best coal is derived.

According to the report of Mr. Bollaert, the Lota coal is largely used in the steam-navigation of the Chilian coast, as also in copper-smelting, iron-foundries, and for domestic purposes. The Lota coal-field is estimated to contain 40 millions of tons, and the Coronel, double that quantity.

A detailed section of the coal-series at Coronel is given by Mr. W. Mundle, throughout a depth

* We have accounts of these strata by Mr. C. Darwin, "Geological Observations in S. America," 1864; by Mr. W. Bollaert, "Observ. on the Coal-formation of Chili," Journ. R. Geog. Soc. xxv., 172; and by Messrs. G. A. Lebour and W. Mundle, Geol. Mag., vol. vii., 499 (1870).

of 587 feet, which shows a series of sandstones and shales, with 9 seams of coal, or lignite, some of which are workable. The eighth seam from the top, nearly 5 feet in thickness, is described as a "very good, hard, and clean coal," which, however, it ought to be remarked, is inferior in quality to true Carboniferous coal of Britain or America. The following are the analyses of these coals:—

	Talcahuano (Admiralty).	Lota, Dr. Playfair.	Lota (first seam), Mr. Abel.
Ash	6·92	5·68	2·05
Carbon	70·71	78·30	83·70
Hydrogen	6·44	5·30	1·02
Oxygen		8·37	
Sulphur	15·93	1·06	13·23
Nitrogen		1·29	
	100·00	100·00	100·00

On the age of these beds some difference of opinion exists; along with representatives of Tertiary genera, such as *Voluta*, *Bulla*, etc., there are Cretaceous genera, such as *Ammonites* (fragments of one specimen), and *Baculites*. On this ground, M. A. D'Orbigny has contended for the Cretaceous age of these carbonaceous deposits, while Mr. C. Darwin thinks it to be one "verging on the commencement of the Tertiary era."

Mr. Bollaert states that coal, similar to that of Chili, has been observed along the Straits of Magellan, and indications of it 30 miles south of Valparaiso.*

* *Supra cit.*, p. 175.

CHAPTER VII.

ANNUAL PRODUCTION OF COAL IN VARIOUS COUNTRIES.

	Tons.
Great Britain and Ireland (1879)[1] . . .	134,008,228
America—United States (1877)[2] . . .	54,398,250
,, Nova Scotia (1879)[3]. . . .	688,626
France (1877)[4]	16,877,200
Belgium (1878)[5]	14,899,175
Germany (Coal and Lignite) (1877)[6] . .	48,296,367
Austrian Empire (1876)[7].	14,252,038
Spain (1873)[8].	699,500
Russian Empire (1876)[9]	1,824,868
British India[10]	500,000

[1] "Mineral Statistics of Great Britain," collected by R. Hunt, F.R.S. Number of Collieries, 3,877.

[2] Saward's Estimate in Spofford's American Almanac, 1880. Number of Collieries, 340.

[3] Communicated by Mr. R. Meade, of the Mining Record Office, London.

[4] "Colliery Guardian," Nov. 1879. Imports in same year, 7,267,300.

[5] Communicated by Professor Dewalque, Liege.

[6] Messrs. Sheafer's Tables, Pottsville. Of this Westphalia produces about 19 millions. "Le Charbon," 1879.

[7] An. des Mines, t. 14.

[8] Sheafer's Tables.

[9] An. des Mines, t. 14.

[10] Communicated by Mr. V. Ball.

		Tons.
New South Wales (1877) [11]		1,444,271
Vancouver Island (1878) [12]		145,542
Queensland (1877) [13]		60,918
Dominion of Canada	Cumberland, Pictou (N. Scotia), Cape Breton (1877)[14]	757,496

The above statements and estimates give an approximate view of the output of coal over the globe, amounting to about 289 millions of tons per annum. Thus mankind by his progress in the arts is gradually restoring to the atmosphere the carbonic acid, which was extracted therefrom during the Carboniferous period. Much of this is taken up and utilized by vegetation; but, as it is probable that the consumption of vegetable matter is at least equal to the growth, there is a tendency towards deoxidation.

The annual increase in the production of coal in the British Isles since the year 1854, is over two and a half millions of tons.† I do not go farther back, because it is doubtful whether much reliance is to be placed on estimates advanced by several authorities earlier than that year, when the "Mineral Statistics of Great Britain," collected by Mr. R. Hunt, were first

[11] [12] [13] [14] From Returns in Colonial Office, by permission of the Rt. Hon. Sir M. Hicks-Beach, Chief Secretary.

† The actual amount is 2·75 million tons.

published. The following are the estimates for each year obtained through this source. It will be observed that the increase is by no means uniform; on the contrary, during the past four years (from 1876 to 1879 inclusive), the output has been practically stationary; a result which I commend to the consideration of Professor Jevons and political economists generally.

Coal-produce of Great Britain, 1854—70.

		Tons.
1854.	England and Wales	57,064,651
	Scotland	7,448,000
	Ireland	148,750
	Total	64,661,401
1855.	England and Wales	56,983,450
	Scotland	7,325,000
	Ireland	144,620
	Total	64,453,070
1856.	England and Wales	59,008,851
	Scotland	7,500,000
	Ireland	136,635
	Total	66,645,486
1857.	England and Wales	57,062,604
	Scotland	8,211,472
	Ireland	102,630
	Total	65,376,706
1858.	England and Wales	57,062,604
	Scotland	8,926,249
	Ireland	120,750
	Total	66,109,603

		Tons.
1859.	England and Wales	61,559,465
	Scotland	10,300,000
	Ireland	120,300
	Total	71,979,765
1860.	England, Wales, Ireland	73,142,198
	Scotland	10,900,500
	Total	84,042,698
1861.	England and Wales	75,203,871
	Scotland	11,081,000
	Ireland	123,070
	Total	86,407,941
1862.	England and Wales	70,434,838
	Scotland	11,076,000
	Ireland	127,500
	Total	81,638,338
1863.	England and Wales	75,064,665
	Scotland	11,100,500
	Ireland	127,050
	Total	86,292,215
1864.	England and Wales	80,262,873
	Scotland	12,400,000
	Ireland	125,000
	Total	92,787,873
1865.	England and Wales	85,377,087
	Scotland	12,650,000
	Ireland	123,500
	Total	98,150,587
1866.	England and Wales	88,881,794
	Scotland	12,748,750
	Ireland	123,750
	Total	101,754,294

		Tons.
1867.	England and Wales	90,249,437
	Scotland	14,125,943
	Ireland	125,000
	Total	104,500,380
1868.	England and Wales	88,304,148
	Scotland	14,709,959
	Ireland	126,950
	Total	103,141,057
1869.	England and Wales	92,882,384
	Scotland	14,417,150
	Ireland	127,923
	Total	107,427,457
1870.	England and Wales	95,355,169
	Scotland	14,934,553
	Ireland	141,470
	Total	110,431,192
1871.	England and Wales	101,747,987
	Scotland	15,438,291
	Ireland	165,750
	Total	117,352,028
1872.	England and Wales	108,010,244
	Scotland	15,383,609
	Ireland	103,463
	Total	123,497,316
1873.	England and Wales	110,055,540
	Scotland	16,857,772
	Ireland	103,435
	Total	127,016,747
1874.	England and Wales	108,140,042
	Scotland	16,788,661
	Ireland	139,213
	Total	125,067,916

		Tons.
1875.	England and Wales	113,141,648
	Scotland	18,597,507
	Ireland	127,950
	Total	131,867,105
1876.	England and Wales	114,554,278
	Scotland	18,665,552
	Ireland	124,936
	Total	133,344,766
1877.	England and Wales	116,151,967
	Scotland	18,320,07
	Ireland	138,72
	Total	134,610,76
1878.	England and Wales	114,637,60
	Scotland	17,837,28
	Ireland	132,97
	Total	132,607,86
1879.	England and Wales	116,409,30
	Scotland	17,469,92
	Ireland	129,00
	Total	134,008,22

PART IV.

CHAPTER I.

AN INQUIRY INTO THE PHYSICAL LIMITS OF DEEP COAL-MINING.

THE reader will have observed that the limit of depth adopted in the estimates of the workable quantity of coal in the individual coal-fields and adjoining districts has been 4,000 feet, notwithstanding that there are hundreds of square miles stored with coal at greater depths than this, which have been estimated by the Royal Commissioners to amount to no less than 48,486 millions of tons.* Now, it so happens that this limit of 4,000 feet, which I adopted in 1860 (on grounds stated in the first and second editions of this work), has also been adopted by the

* The quantity obtained by adding the amount of 7,342,000,000 tons included in the known coal-fields, to 41,144,000,000 tons in districts overspread by newer formations.—Report, vol. I., pp. ix. and xvii.

Royal Commissioners, as the greatest depth to which mining operations are ever likely to extend. This concurrence of views on a subject bearing so directly upon the question of the exhaustion of our coal-resources is gratifying to myself, and will probably be regarded by the public at large as a ground of confidence in the conclusions arrived at by both parties.

The two main impediments to the prosecution of mining operations at great depths are:—the increase of temperature in the strata themselves, and the pressure due to the weight of the strata; but as the latter obstacle is capable of being overcome in most cases, especially under the "long-wall system" of mining, it may be omitted from consideration;* and we may concentrate our observations on the subject of the increase of temperature alone.

That the temperature of the earth's crust increases as we descend, is a proposition which has been determined in the affirmative by observations extending over a large portion of the land-surface itself. It is, however, to be observed, that, compared to the radius of the earth,

* The Report of the Coal-Commission scarcely alludes to this subject, and it is probable that the Commissioners did not consider it necessary seriously to entertain it.

these observations extend only to a very small depth; nevertheless, they are perfectly sufficient for determining the problem, as far as it is calculated to influence the question of deep mining, though not as regards the physical constitution of the interior of our globe. The following cases of special interest may be here stated.

Foreign Countries.—Numerous experiments with the object of determining the rate of increase of temperature have been made on the Continent—of which, however, only the results can here be given.

1. The temperature of the water of the Puits de Grenelle, near Paris, rising from a depth of 1,903 English feet is 81·95 Fahr., giving a rate of increase of about 1° Fahr. for every 59·9 feet.*

2. At Mondorff, in the Grand Duchy of Luxemburg, there is an Artesian boring passing through several formations, which gave a result of 1° Fahr. for every 57 feet.

3. The Well at St. André, 50 miles W. of Paris, gives a result of 1° Fahr. for every 56·4 feet.†

4. The Well of La Chapelle at Paris, at a depth of 600 metres, gives a result of 1° Fahr. for every 84 feet.‡

* Prof. Everett, Brit. Assoc. Rep. 1871, p. 24.

† *Ibid.* ‡ *Ibid.*, Rep. 1873, p. 253.

5. Boring at Sperenberg near Berlin, to a depth of 4,172 feet, nearly all in rock-salt, gave at a depth of 3,390 feet, a result of 1° Fahr. for 51·5 English feet.*

Great Britain.—Kentish Town (London). In the well sunk for water supply, the temperatures have been carefully taken by Mr. G. J. Symons, between the depths of 350 and 1,100 feet, at which the depth was found to be 69·9° Fahr., giving the mean rate of increase from the surface of the ground at about 1° Fahr. for every 54 feet.†

Monkwearmouth Colliery.—Professor Phillips some years since made observations on the temperature at this colliery, which have shown an increase of about 1° for every 60 feet.

Boldon Colliery near Newcastle-upon-Tyne.—Two sets of observations were made in dry bore-holes sunk from the floor of the colliery by Mr. M. Heckels, the Manager, in 1876, and gave the following results:—

Surface	. 48° Fahr.
Depth of 1365 feet . . .	. 75° Fahr.
,, 1514 ,, . . .	. 79° Fahr.

* Herr Dunker, quoted by Everett. *Ibid.*, Rep. 1876, p. 206. Other Continental cases will be found in these valuable Reports down to 1878.

† *Ibid.*, Rep. 1871, p. 17.

For the interval of 149 feet between the two holes we have an increase of 4° Fahr., which is at the rate of 1° Fahr. in 37 feet. For the whole depth of 1514 feet we have an increase of 31° Fahr., which is at the rate of 1° Fahr. in 49 feet.*

Dukinfield Colliery.—The experiments carried out by Mr. Astley, during the progress of sinking the Dukinfield Colliery, are perhaps the most valuable of any hitherto undertaken in this country. Through the kindness of the late Dr. Fairbairn, of Manchester, I have been supplied with the whole of the details, which I here insert at length. The observations were conducted with great care. The thermometer was inserted in a dry bore-hole, and removed as far as possible from the influence of the air in the shaft, and left in its bed for a length of time, varying from half an hour to two hours. The results also carry with them more than usual importance, from the fact that they extend downwards to a depth of 2,055 feet, with an additional observation made in the open workings, at 120 yards from the shaft, and at a depth of 2,151 feet.

* Communicated by Mr. Lebour to Prof. Everett, Brit. Assoc. Rep. (1877), p. 197.

Thermometrical Observations in the Dukinfield Colliery, Cheshire, between 1848 and 1859.*

Date.		Depth in Yards.	Temperature Fahr.	Description of Stratum.
1848.				
July	28th ..	5·6	51°	Red rock—no variation.
1849.				
	1st	231	57·7	Blue shale—wet
	12th	234·7	58	ditto dry hole
	16th	237	58	ditto ditto
July	14th	239	57·5	
,,	16th	240	58	ditto ditto
,,	27th	242	57·5	ditto ditto
August	9th	244	58	ditto ditto
,,	25th	248	58	ditto water
,,	27th	248	57·25	ditto ditto
,,	31st	250	57·25	ditto ditto
November	14th	252	58	
December	6th	256·5	58	Blue shale—dry
,,	15th	262·5	58·5	ditto ditto
,,	22nd	270	58	Bituminous shale—dry
1850.				
January	9th	279	58·5	Strong warrant earth
,,	26th	286·5	59·12	Rock bands
February	11th	293	59·5	Coal roof
,,	19th	300	59·87	Warrant earth
March	5th	309	59·87	Purple mottled shale
1851.				
June	9th	358	62·5	Warrant earth
August	14th	373	64	Tender blue shale
November	7th	403	65	Coal roof
,,	19th	419	65·37	Rock bands
1852.				
February	6th	433	66·5	Black shale
May	28th	446	67	Strong fire-clay
1857.				
February	28th	483·5	67·25	Sandstone—dry hole
March	7th	487	67·76	Shale
April	11th	501	68·5	Sandstone
May	6th	511·5	68·75	Blue shale
,,	19th	521·5	69·38	Strong shale
June	9th	533	69·75	Warrant earth
,,	22nd	539	69·88	Blue shale
,,	27th	546	71·75	Coal and earth
July	18th	555	71·25	Grey sandstone

* These observations are published by Dr. Fairbairn, F.R.S., in the Report of the British Association for 1861.

THERMOMETRICAL OBSERVATIONS, ETC.—(*Continued.*)

Date.		Depth in Yards.	Temperature Fahr.	Description of Stratum.
August	1st	563	72·25	Red rock (sandstone)
,,	15th	569	71·25	ditto wet hole
September	2nd	578	72·12	ditto ditto
,,	19th	589	71·5	ditto ditto
October	3rd	597	72·25	Grey rock—dry hole
,,	17th	608	72·25	Coal roof—wet hole
,,	27th	613·5	72·25	Coal floor ditto
1858.				
March	22nd	621	72	Strong shale—dry
,,	29th	627	71·5	Dark-blue shale
April	23rd	645·5	72·25	Shale—dry hole
May	1st	651	72·25	ditto ditto
,,	19th	658	72·5	ditto ditto
June	9th	669	73·25	Bituminous shale—dry hole
,,	19th	673	74·12	Grey rock
July	17th	683	75·25	Blue shale
,,	21st	685	75·5	do. do.
1859.				
March	5th*	717	75·0	"Black Mine" Coal roof

1. The first observation gives 51° as the invariable temperature throughout the year at a depth of 15½ feet.† Between 231 yards and 270 yards, the temperature was nearly uniform at 58·0, and the increase from the surface would be at the rate of 1° Fahr. for 88 feet.

* In workings at 120 yards down engine incline from the shaft.

† This observation for the position of the invariable stratum is probably not reliable. The depth ought to be greater, but its accurate determination requires a series of observations which could not well have been made in the present instance.

2. Between 270 and 309 yards, the increase was at the rate of 1° for 62·4 feet.

3. Between 309 and 419 yards, the increase was at the rate of 1° for 60 feet.

4. Between 419 and 613 yards, the increase was at the rate of 1° for 86·91 feet.

5. Between 613 and 685 yards, the increase was at the rate of 1° for 65·6 feet.

6. The last observation, taken in the mine itself, at 120 yards from the pit, is valuable, as showing that the temperature of the air does not greatly differ from that of the surrounding strata.

The result of the whole series of observations (making allowance for the doubt regarding the first observation) gives an increase of about 1° for every 80 feet, which is a less rapid increase than that exhibited by the generality of experiments. But before discussing the cause of this abnormally slow rate of increase I wish the reader to become acquainted with the experiments of not less interest and value made at another colliery near Wigan, and extending to a still greater depth, and in the same parallel of latitude.

Rose Bridge Colliery, Wigan.—The following observations on the temperature of the strata during the progress of sinking the pits of Rose Bridge Colliery, at Ince, near Wigan, now the

deepest mine in Britain, have been communicated to the author by Mr. Bryham, the Manager, by whom they were carried out. They differ materially from those of Dukinfield just described.*

THERMOMETRICAL OBSERVATIONS AT ROSE BRIDGE COLLIERY.

Date.	Depth in Yards.	Strata.	Temperature in open pit.	Temperature in solid strata.
			° F.	° F.
July 1854	161	Blue shale	...	64·5
August 1854 ...	188	Warrant earth ...	...	66
May 1858	550	Blue shale	...	78
July 1858	600	Warrant earth ...	...	80
May 18, 1868 ...	630	"Raven" coal ...	73	83
July 24, 1868 ...	665	Strong shale ...	75	85
April 19, 1869 ...	673	"Yard Coal" mine	76	86
November 18, 1868	700	Strong blue metal...	76	87
February 22. 1869	736	Do.	76	88½
March 12, 1869 ...	748	Shale	77	89
April 17, 1869 ...	762	Linn and wool, or strong shale ...	78	90·5
May 3, 1869 ...	774	Strong shale ...	80	91·5
May 19, 1869 ...	782	Blue metal	79	92
July 8, 1869 ...	801	Strong blue shale ...	79	93
July 16, 1869 ...	808	Coal (Arley mine)...	79	93½

Assuming the surface temperature to be 49°, we have on the whole depth of 808 yards, or 2,424 feet, an increase of 44·5°, which is at the rate of ·0184 of a degree per foot, or one degree

* These observations, with a complete section of the strata to a depth of 815 yards from the surface, are given in the "Third Report of the Committee on Underground Temperature," Rep. Brit. Assoc., 1870.

for every 54·4 feet, as against one degree for every 80 feet at Dukinfield.

Cause of difference in rate of increase.—With strata so nearly similar, and in two neighbouring counties, we should scarcely have expected so much difference in the mean rates of increase downwards. In this respect, Rose Bridge agrees nearly with the average results obtained elsewhere; Dukinfield far surpasses all other deep mines or wells, so far as our present records extend, in slowness of increase.*

In a paper published in the Proceedings of the Royal Society of London,† I have endeavoured to show that the cause of the discrepancy in the results obtained at the two localities is due to the differences in the position of the strata in each case. At Rose Bridge the beds are nearly horizontal, at Dukinfield they are inclined at an angle varying from 30° to 35°, rising and cropping out to the eastward. Now, strata of various kinds, such as alternating sandstones, shales, clays, and coal, with different conducting powers, must offer more resistance to the transmission of heat in a direction across, than parallel to, their planes of bedding; for Mr. Hopkins has

* *Ibid.*, p. 32.

† Proc. Royal Society, 1870, vol. xviii., p. 175.

shown, that every sudden change of material is equivalent to an increase of resistance; and it is obvious that highly-inclined strata, such as those at Dukinfield, furnish a path by which internal heat can travel obliquely upwards and outwards, without being interrupted by these breaches of continuity. On the other hand, deep-seated horizontal strata, like those of Rose Bridge, offer a succession of resisting surfaces to the upward passage of internal heat.

As, therefore, the rate of increase of temperature is inversely proportional to the upward flow of the heat, we have here a solution of the results arrived at in the cases before us. To this it may be added, that inclined strata furnish great facilities for the convection of heat by the flow of water along the planes of junction.

The general inference which may be drawn from the cases just described, as far as they bear upon the temperature of coal-mines, is this: that in those districts where the strata are highly inclined (at angles varying from 30°—60°), the underground temperature will be lower than in the case of those where the strata are in a position approaching the horizontal.

Mean Result.—The illustrations already adduced will probably be considered sufficient to

show that the increase of temperature is a reality, which becomes a sensible obstacle at a slightly variable depth; and will have to be encountered and overcome by artificial means when the depth exceeds 800 or 900 yards. On this point the Commissioners on Coal-resources have arrived at the conclusion that at a depth of 1,000 yards (3,000 feet) the temperature of the earth would amount to 98°. Under "the long-wall system" of working, a difference of about 7° appears to exist between the temperature of the air and that of the working faces, and this difference represents a further depth of 420 feet; so that the depth at which the temperature of the air would, under the present conditions, become equal to the heat of the blood, would be about 3,420 feet. Beyond this point the considerations affecting increase of depth become so speculative, that the Commissioners leave them in uncertainty; but they consider it may be fairly assumed that a depth of at least 4,000 feet may ultimately be reached in coal-mining.*

In reviewing the evidence laid before them by several gentlemen of experience, the Commissioners have come to the conclusion that the rate

* Report, vol. i., p. 88.

of increase may, for ordinary cases, be assumed to be 1° Fahr. for every 60 feet. From this mean result there will be variations, as in the case of Dukinfield and Rose Bridge; one of which gives a less rapid, the other a more rapid, rate of increase. Assuming, however, the rate as above stated, it is necessary to determine the temperature to which the addition of 1° for 60 feet is to be made, in order to calculate the temperature at different depths; in other words, the position of the "*invariable stratum.*"

Now, it has been found that at a certain depth, varying from 30 to 50 feet, the temperature remains the same all the year round; and is nearly that of the mean annual temperature of the place. The depth of this "invariable stratum," according to Humboldt, depends upon the latitude of the place (increasing from the equator towards the poles), on the conducting power of the rock, and on the amount of difference between the temperatures of the hottest and coldest seasons. At Greenwich, the mean temperature is 49·5°; and in the deepest of several underground thermometers, 25 feet from the surface, the extreme variations were (1858) from 48·85° to 52·27°, giving a mean of 50·56°—a result, differing by only half a degree from

that of Dukinfield Colliery, obtained ten years earlier.*

We may therefore adopt 50·5° as the standard of departure—or in other words the *temperature of no variation* at a depth of about 50 feet underground.

But there is an additional element tending to raise the heat in deep mines; namely, the increased density of the air. The effect of this will be greatest when the air is stagnant; but when there is a rapid circulation of the air-current it will probably be small, and may be disregarded.†

The following Table gives the maximum temperature at the various depths according to the average rate of 1° Fahr. for 60 feet:—

Table showing Theoretical Increase of Temperature.

Depth in Feet.	Increase of Temperature due to depth.	Depth in Feet.	Increase of Temperature due to depth.
1,000	63·0 ° F.	2,750	95·5 ° F.
1,500	73·8	3,000	99·6
1,750	78·8	3,250	103·8
2.000	82·0	3,500	108·0
2,250	87·1	3,750	112·1
2,500	91·3	4,000	116·3

* "Greenwich Observations" for 1858.

† This element has not been noticed by the Commissioners, though I drew attention to it in the second edition of this work

From the above Table it will be observed, that at a depth of 3,000 feet the temperature of the strata exceeds that of blood heat, and that were it not for the effects of ventilation in reducing the temperature, the limits of coal-mining would be circumscribed within this depth.

Ventilation.—To effective ventilation, however, we must look for ability to win those seams which lie within the additional thousand feet of strata; and, as to what extent this is likely to be accomplished, we have already some valuable evidence. In reference to the effect of the heated walls of the rock on the ventilating air-current, the Commissioners remark as follows:*—When cool air enters a heated mine it absorbs heat from the surfaces of the passages through which it flows, and the rate of this absorption somewhat exceeds the ratio of the difference between the temperature of the air and that of the surrounding surface with which it is in contact. By the absorption which thus takes place the air is heated, and this heating process is

From this I infer that the Commissioners did not consider the increased density of the air in a well-ventilated mine as calculated materially to increase the temperature.

* Report, vol. i., p. 82 (Committee A, of which Sir W. C. Armstrong, C.B., was chairman).

most rapid at first, when the difference of temperature is greatest, and gradually diminishes as the length of the passage is extended, never ceasing until complete assimilation of the temperature is effected. The progress towards assimilation is more rapid when the air comes in contact with the working face of the coal, which, from being newly exposed, is more highly heated than the surfaces of the permanent air courses. The rapidity, however, with which the air takes up the heat from the working face depends in a great degree upon the system of working. In the cellular system, called "pillar and stall," the air seems to acquire almost immediately the full temperature of the coal; but under the "long-wall" system there are instances of the air retaining a considerable inferiority of temperature after sweeping past the working face.

Temperature of Air-current.—The experiments made by Mr. Bryham, the Manager of Rose Bridge Colliery, near Wigan, for the purpose of determining the rate of increase of temperature of the air-current while flowing through the passages of a deep mine, are of much interest. They are taken at the respective depths of 300 and 600 yards, and at different periods of the year, and are as follows:—

OBSERVATIONS ON TEMPERATURES OF AIR CURRENTS, ETC., AT ROSE BRIDGE COLLIERY, WIGAN.

Temperature at Surface in Shade, 56°.

Date.	Depth in Yards.	Air current. Cubic ft. per min.	Temperature of intake air.	Temperature of return air.	Gain of heat.	Distance travelled by the current.
1860. Sept. 4th	300	35·00	59·5	64·0	5·5	1,000 yards
"	...	...	...	68·0	8·5	4 yards out of air-current
"	600	81·76	60·5	73·0	12·5	1,500 yards
"	...	...	...	75·0	15·0	8 yards out of current

Temperature at Surface in Shade, 42°.

Date.	Depth in Yards.	Air current. Cubic ft. per min.	Temperature of intake air.	Temperature of return air.	Gain of heat.	Distance travelled by the current.
1861. Mar. 18th	600	105·58	50·75	...	...	Main intake.
"	...	96·40	...	68·75	18·0	Taken in Dumb Drift; distance travelled, 2,200 yards.
"	...	23·26	51·5	67·5	16·0	Distance travelled, 2,400 yards.
"	...	31·50	51·0	...	...	
"	...	21·00	...	71·0	20·0	Distance travelled, 3,140 yards.
"	...	10·50	...	67·5	16·5	Distance travelled, 1,900 yards.
"	...	...	60·0	...	...	4 yards out of main intake air.
"	...	...	...	71·75	11·75	4 yards out of main return air.

Barometer in Cannel Mine (600 yards) 30·5, at surface 28·8.

The above experiments bring out many points of interest. 1. We cannot but be struck with the enormous amount of caloric continually

being carried off from the mine. Thus, in one of the experiments, it is shown that at a depth of 600 yards, a current of air equal to 21 cubic feet per minute passes off from the mine 20° warmer than it entered, after circulating through 3,140 yards. 2. It will be observed that the surface temperature, depending upon the season of the year, materially affects the temperature of the whole mine; and, if the extreme temperatures of summer and winter had been observed, the results would doubtless have been proportionate. Thus, with a surface temperature of 56°, the return air is 73° with 1,500 yards of circulation, while with a surface temperature of 42°, the return air is only 67·5° with 1,900 yards. 3. The increase of heat received by the air while passing down the shaft appears to be considerable. Thus in a depth of 300 yards the increase was 59·5—56=3·5°, and in a depth of 600 yards the increase was 60·5—56=4·5° in September, and 50·75—42=8·75 in March. Lastly: Several observations show how powerful is the air-current in moderating the temperature; for, whenever the thermometer was placed beyond its influence, the mercury immediately ascended. All these points bear directly upon the question of deep mining.

Effects of the Seasons.—It might have been supposed that the influence of the comparatively colder air of winter and warmer air of summer would be felt throughout the workings of a coal-mine, but the Commissioners have come to a different conclusion, upon the evidence offered them on this subject. All the witnesses examined agreed in stating that summer and winter make no difference in the temperature of the air in mines, except at short distances from the shaft. This is due to the fact, that great disparity of temperature is rapidly reduced when the air comes in contact with the air passages: thus, very cold air upon entering the mine rapidly absorbs the heat of the strata, and the greater the difference of temperature the more rapid is the absorption. I am, therefore, induced to abandon an opinion which I formerly held, that air at a low winter temperature might be, in some cases, rendered available for mines which in the summer months might become unworkable.

Effect of the increased circulation of Air-current.—On this subject the evidence offered chiefly by Mr. Lindsay Wood, of Hetton Hall; Mr. J. J. Atkinson, of Chilton Moor; and Mr. John Knowles, of Pendlebury, has tended to

show that little change of temperature is effected by increasing the circulation of the air in the passages of the mine. From the tabulated statement given in the report, it appears that in one case observed at Hetton Collieries, when the distance from the shaft was from 2,296 to 2,925 yards, the difference between temperature of the strata and of the air was only 2°, while the volume of air in circulation was 22,400 cubic feet in one case, and 11,400 in another.

Mr. Wood has shown by a table the gradual approximation of the temperature of the air to that of the strata through a distance of 3,422 yards; and he found that at that distance no perceptible difference took place in the temperature of the current when reduced from 41,800 cubic feet to 3,000 per minute.

Effect of Humidity or Dryness of the Air.— The question of the maximum temperature of air which is compatible with healthful labour is an exceedingly difficult one to determine, and the Commissioners had evidence laid before them showing that in some cases human labour had been carried on at temperatures as high as 180° Fahr.; but it was observed, that in these cases the thermometer indicated radiant heat, and not that of the surrounding air. Upon one

question, however, the witnesses were unanimous: that a high temperature was endurable very much in proportion to the dryness of the air; while on the other hand, where it was saturated with moisture, the same degree of temperature became intolerable.

Now, it is a matter of general observation, that in deep mines the air is comparatively dry. The water, which is generally present, often in large quantities in shallow mines, gradually lessens in quantity as we descend, and at depths of 500 or 600 yards ceases altogether. The air, therefore, which circulates through the passages of deep mines gradually parts with its moisture while it rises in temperature, and passes into a state agreeable to the human system, and conducive to health. The hygrometric condition of the air in deep mines may, therefore, be regarded as in some measure tending to counterbalance the effects of a high temperature, and to render possible healthful labour at great depths from the surface.

The following Tables of observations on this subject are of much interest, and are extracted from the Report of the Royal Commissioners:—

No. 1.—Summary of Hygrometric Observations in Coal Mines in Lancashire, North Wales, Cheshire, Staffordshire, and Yorkshire.

Name of Mine.	Place of Observation.	Depth in Feet.	Distance from Downcast Shaft, in Yds.	Dry Bulb.	Wet Bulb.	Relative Humidity, 100° being Saturation.
Rose Bridge Colliery ..	End face of a level	2.391	69	71°·0	64°·5	68·3
	Do.	2,391	103	72·5	65·5	66·8
	Do.	2,391	303	75·0	68·0	68·1
Pendleton Colliery ...	A working face	2.064	1.747	81·0	73·0	66·5
	Do.	2,214	727	77·0	69·0	64·8
Astley Pit, Dukinfield Colliery	Do.	2,216	590	73·0	69·0	80·7
Astley and Tylesdale Colliery	Face of level	1.200	2,035	69·0	69·0	100·0
Bank Colliery	A working face	900	120	68·0	67·0	94·7
Low Side Colliery ...	Do.	492	586	60·0	60·0	100·0
Anderton Hall Colliery	Face of level	900	600	63·0	62·0	94 3
Bradleyfold Colliery ...	A working face	540	1,520	70·0	69·0	94·8
Wynnstay Colliery, North Wales	Do.	1.173	611	67·0	66·0	94·6
Hafod Colliery, North Wales	Do.	1.815	195	75·0	73·0	90·4
	Do.	1.452	390	72·0	70·0	90·0
Clifton Hall Colliery ...	Do.	1,640	1,262	69·0	63·0	70·0

Remarks.—In the Tables from which this Summary is compiled the depth is stated in yards, and the distance travelled by the air computed from the mouth of the shaft. To facilitate comparison with the Durham observations, the depth is here expressed in feet, and the distance travelled is taken from the bottom of the shaft.

No. 2.—SUMMARY OF HYGROMETRIC OBSERVATIONS IN COAL MINES IN THE COUNTY OF DURHAM.

Name of Mine.	Place of Observation.	Depth in Feet.	Distance from Downcast Shaft, in Yds.	Dry Bulb.	Wet Bulb.	Relative Humidity, 100° being Saturation.
Jane Pit, Eppleton Colliery	A working face.	1,395	4,332	73°5	73°5	100·0
	"	1,395	4,440	74·0	74·0	100·0
	"	1,395	4,560	74·5	74·5	100·0
Caroline Pit, Eppleton Colliery	"	838	2,560	64·0	64·0	100·0
	"	1,040	3,364	65·5	65·0	97·2
	"	1,012	3,328	65·5	65·0	97·2
	"	1,030	3,365	65·0	65·0	100·0
Lady Pit, Elemore Colliery	"	970	1,866	67·5	67·5	100·0
	"	930	2,660	66·0	66·0	100·0
Wharton Colliery ...	"	88	3,454	65·0	64·5	97·2
	"	900	4,246	64·5	64·0	97·2
	"	924	3,696	68·0	67·0	94·7
	"	1,254	1,826	71·75	70·0	91·0
Monkwearmouth Colliery	"	1,646	3,256	81·25	79·5	92·0
	"	1,640	3,216	82·25	81·25	95·6
Ryhope Colliery ...	"	1,560	2,762	73·0	71·0	90·2*
Murton Colliery... ...	"	1,374	4,532	70·0	69·5	97·4
Monkwearmouth, 2nd observation	"	1,646	3,256	81·0	78·0	86·8†
	"	1,640	3,216	81·0	78·0	86·8
Monkwearmouth Colliery, 3rd observation	"	1,646	3,256	81·0	74·0	70·4‡
	"	1,640	3,216	81·0‡	77·0	80·6
Seaham Colliery ...	"	1,995	2,200	78·0	76·0	60·3

* Under the sea. † These observations were taken by Mr. L. Wood and Mr. Dickinson conjointly.

‡ It is the practice in this colliery to water the roads to keep down the dust, but this practice had been suspended for eleven days immediately preceding this 3rd set of observations.

Effects of Pressure.—It is impossible to speak with certainty of the effect of the accumulative weight of 3,000 or 4,000 feet of strata on mining operations. In all probability, one effect would be to increase the density of the coal itself, and of its accompanying strata, and so to increase the difficulty of excavating. Coal-mining labours under a disadvantage not felt in mining other minerals, namely, the impossibility in general of having recourse to blasting. The increased firmness of the strata will most assuredly be felt at great depths; but the question whether the resistance will prove beyond the powers of manual skill and mechanical contrivances to surmount, can only be solved by actual experience. I am informed by Mr. Bryham, that from his experience the density of coal-seams is not perceptibly greater at 500 or 600 yards than at half that depth; at the same time, in Dukinfield Colliery, where the Black Mine is now being worked at a depth of about 2,500 feet, the pressure is so powerful as to crush in circular arches of brick four feet in thickness, and in one case, a pillar of cast iron 12 inches square, supporting a roof of only seven feet in extent, was snapt in twain! *

* As I was informed by Mr. Seddon, the underlooker.

In the face of these two obstacles—temperature and pressure, ever increasing with the depth—I have considered it utopian to include in calculations having reference to coal-supply, any quantity, however considerable, which lies at a greater depth than 4,000 feet. Beyond that depth, I do not believe it will be found practicable to penetrate. The physical barriers appear insurmountable.

CHAPTER II.

THE DURATION OF OUR COAL-SUPPLY.

When in 1860 I attempted to calculate the quantity of British coal, and arrived at the conclusion that there were 79,843 millions of tons, down to a depth of 4,000 feet, I was able to assure the public that there was sufficient coal to last, at the rate of production for that year, for one thousand years. Ten years later the Royal Commissioners, appointed under an Act of Parliament, by a division of labour, and with facilities which no private individual could command, made another and more detailed series of estimates, and returned the quantity at nearly double the amount arrived at by myself within the same limit of depth, namely, 146,480 millions of tons. The discrepancy in the two results was chiefly due (1) to the Commissioners having included in their calculation coal-seams between one and two feet in thickness, purposely omitted by myself; (2) to the Commissioners having made a smaller deduction for waste and loss in

the working of the coal; and (3) to the Commissioners having boldly estimated the quantities under certain districts overspread by formations newer than the Carboniferous, which I hesitated to deal with; not because I doubted the existence of the coal there, but from a fear of overstating the case. With the course adopted by the Commissioners in the two last cases, I now fully concur; but I still object to the comprehension of seams under 24 inches in thickness in estimates of the available quantities at great depths.

The propriety, or the contrary, of this course on the part of the Commissioners does not, however, very materially affect the question of the coal-resources of Britain and the duration of our coal-supply; and it must be satisfactory to the nation at large to be assured, on the authority of the eminent men who gratuitously undertook the laborious task confided to them by their Queen and country, of the existence of such vast quantities of mineral fuel reserved for future use.

Annual Increase of Consumption of Coal.—With reference, however, to the duration of our coal-supply, the Commissioners cautiously avoid giving a definite answer to the question, "How

long will our coal-supplies last?" for the excellent reason that it is a question to which a definite answer cannot be given. We know, indeed, the extent of our resources in millions of tons, but we know not the extent of the future drain upon these resources. The drain upon our coal-fields, however, is increasing year by year, and will doubtless continue to increase for a long time to come. This is due to several causes; let us examine a few of them.

1. The present consumption of coal for domestic use has been estimated by Mr. Robert Hunt at one ton per head per annum of the whole population, and may be assumed to absorb nearly one-third of the entire quantity raised from the mines. It is thought probable by the Commissioners that this rate will continue pretty constant; and the future increase of consumption under this head may, therefore, be expected to coincide with the increase of population.

Now, although the population of these islands is annually increasing, yet it has been ascertained that the increase is taking place at a diminishing rate; for between the years 1811 and 1821 the increase was 16 per cent., while during the last decade, between 1861 and 1871, the increase was only at the rate of 11·75 per cent.

But while the population is increasing in a diminishing ratio, the rate of increase of coal consumption (though irregular) amounts on an average of the increase of the last 25 years, to 2·774 per cent. per annum. This increase is attributable chiefly to two causes:—first, the town population, which represents the chief coal-consuming portion, is increasing in a far more rapid ratio than the population of the kingdom generally; and secondly, the extension of machinery, the increasing use of coal-gas, and the improvements for encouraging labour, cause the consumption of coal for productive purposes to constantly increase relative to the number of persons employed in manufactures.*

Professor Jevons, who has written an important work on the duration of our coal supply,† has shown that every improvement for the economising of labour has resulted in increasing the consumption of coal; and he contends, that coal being the source of power, and being required for every great extension of industry, the

* Report of the Coal-Commissioners, vol. i., xv. In 1855, the amount of coal consumed per head of the population was only 2 tons 14 cwts., while in 1869 it amounted to 3 tons 17 cwts. 1 qr.

† "The Coal Question," by W. Stanley Jevons (1865).

consumption of it must keep pace with the progress of population, and the extension of manu factures and industrial pursuits. Applying his views to the future consumption of coal, he anticipated in 1865, that in the year 1871 the consumption would be found to amount to 118,000,000 tons, as against 83,500,000 tons in 1861. This calculation has been very nearly verified—for we find that the actual output in 1871 was 117,352,028 tons,* a close approximation, and one showing that Professor Jevons' views have a basis of truth so long as there are not disturbing causes at work, such as have been in operation during the last few years.

On the other hand, Mr. Price Williams, whose views are quoted by the Commissioners,† is of opinion that the present rapid increase in the annual production of coal is mainly in consequence of the equally rapid and abnormal development of our commercial activity, which has followed the introduction of steam power into this country; and that the effect of this initial increase in the annual yield of coal is still perceptible, just as it is, in a minor degree, in the present rate of increase of our population.

* Mineral Statistics, 1871.

† Report, p. xv.

From this he concludes that the rate of increase of coal used *per head* of the population follows a diminishing ratio analogous to that shown by the curve of population.*

On the basis of these diminishing ratios, Mr. Price Williams has calculated that the annual consumption at the end of a hundred years would amount to 274 millions of tons, and that the total quantity of available coal would only last for 360 years.

Upon the basis of an arithmetical increase of three millions of tons per annum (the increase of the 14 years ending 1871), the consumption at the end of a hundred years would be 415 millions of tons, and the estimated available quantity would be only sufficient to last for 276 years.

Both these views, however, labour under the defect that they do not take into account the diminishing ratio at which coal must be consumed, when it becomes scarcer and more expensive. The abrupt exhaustion of our coal-fields is an impossibility; and if it is to take place at all, it can only be by a slow and gradual process—concomitant with a complete, let us hope a higher and nobler, reorganization of society.

* Report, vol. i., p. xv.

Waste in Combustion.—Coal of all kinds is now becoming of such value, that the reprehensible waste in using it, which some years ago was common and notorious, is gradually becoming a thing of the past; and the constant effort of manufacturers, and those engaged in the smelting of metallic ores, is directed towards reducing the expenditure of fuel to a minimum. All, however, which is possible in this direction has not yet been effected; but it is not to be expected that the amount of saving will be very considerable under this head, and the Commissioners report,* that in some branches of manufacture the limits of a beneficial economy appear to have been nearly reached, and that in other cases a gradual effort will continue to be made for saving fuel.

The smelting of iron presents the most remarkable illustration of the extent to which fuel is now being economised as compared with former times. At the Clyde iron-works in 1796, according to the account of Mr. Mushet, no less than 9 tons 10 cwts. and 24 lbs. of coal were consumed for the production of one ton of pig iron. The quantity of coal now consumed (in 1870) has been reduced to 1 ton 14 cwts. 2 qrs. with the

* Report, vol. i., p. 93.

hot blast, or 2 tons 3 qrs. of coke. In the Middlesborough district, where the expenditure of fuel has been reduced to a minimum, the quantity of coal and coke combined amounts to 33 cwts. 1 qr. to the ton of pig iron.

Waste in Working.—It is, on the other hand, much to be regretted that the report of the Commissioners on this head is not of so favourable a character as on the former. It appears that notwithstanding considerable improvements in the general system of coal-mining, and the application of small coal, or slack, to useful purposes, "coal is still wasted by bad working and by carelessness, and that to a very considerable amount in proportion to the quantity actually used."*

At present, under favourable systems of working, the ordinary and unavoidable loss is about 10 per cent., whilst in a large number of instances, when the system of working practised is not suited to the peculiarities of the seams, the ordinary waste and loss amount to sometimes as much as 40 per cent., of which the chief cause is the crushing of the pillars left under the "pillar-and-stall" or cellular system of mining. There are also other sources of waste pointed out by

* Report, vol. i., p. 116

the Commissioners which come under the head of *avoidable*. Thus, properties in themselves too small for a separate colliery, or a small estate traversed by a large fault, and, in consequence, passed by during working of the adjoining coal, is often swamped, or has its coal crushed. Coal is often left unworked through the contention amongst adjoining owners as to which of them should pump the water; of this South Staffordshire affords an unhappy example. Barriers are left round small properties, or crooked boundaries; whereas a barrier properly laid out would be more economical. Lastly, large tracts of coal of uncertain area are left as barriers against the influx of water, in the absence of reliable plans showing the extent of the coal that has been worked; and main faults, which should serve as natural barriers, are often recklessly cut through, and the coal on the other side thereby flooded.

The Commissioners are not prepared to recommend the interference of Parliament in order to deal with these sources of waste by special enactment; but few will be disposed to deny that a large amount of moral responsibility attaches to those who thus wilfully or negligently waste the national resources.

The Remedy.—The cause of much of the

waste arises from the defective system of mining in consequence of the ignorance of many of the mine managers both as regards the theory and practice of their profession. In some districts, without doubt, coal-mining is even now carried on with a high degree of skill; and in Lancashire, for instance, the amount of waste has been reduced to a very small proportion of the quantity extracted. But in other districts it is frequently very different, and it must be acknowledged that mine managers are, as a class, without much education, and ignorant of those theoretical principles upon which practice ought to be founded.

It, therefore, becomes a matter for consideration, whether the Legislature should not establish some educational test, without which no person should be permitted to have the supervision of a colliery, as far as the actual working arrangements are concerned. The schools of mining which have been founded in various districts offer suitable opportunities for the necessary training, as also some of the educational establishments under the Science and Art Department; but, unless the compulsory principle be introduced, experience has shown that the advantages offered by such institutions will not be fully seized by the mining population.

PART V.

CHAPTER I.

PHYSICAL GEOLOGY OF THE CARBONIFEROUS ROCKS.

South-Easterly Attenuation of the Coal-Measures of the North of England.—The investigation of the original manner of distribution of the Carboniferous Rocks is one of much interest to the physical geologist, while it also possesses a certain economic importance. The exact information which the extension of the Geological Surveys over the centre and north of England has afforded, enables us to arrive at definite conclusions on this subject.

Having on former occasions gone very fully into the details,* I shall here content myself with showing that a comparison of a series of sections of the Coal-measures and Millstone series,

* In my paper "On the Thickness of the Carboniferous Rocks of the Pendle Hills, etc.," Journn. Geol. Soc. Lond., vol xxiv., p. 319 (1868).

taken from North Lancashire into Leicestershire and Warwickshire, shows, that along this line the strata undergo a most remarkable amount of attenuation; from which it may be inferred that they have been deposited according to a definite plan, depending on certain physical relations, and the distribution of land and sea during the Carboniferous period. The following comparative sections will render this apparent:—

*Comparative Vertical Sections of Carboniferous Strata.**

	Burnley District, North Lancashire. N.N.W.	Mottram District, East Cheshire.	North Staffordshire.	Leicestershire and Warwickshire. S.S.E.
Coal-Measures ...	8,460	7,630	6,000	3,000
Millstone Grit series	5,500	2,500	500	100 to 300
Yoredale series ...	4,670	2,000	2,300	
Total in feet ...	18,630	12,130	8,800	3,100 to 3,300

From the above comparative sections it will be observed that the beds which attain to so grand a development in North Lancashire, have dwindled down to nearly one-sixth of their volume in Leicestershire, in proximity to the concealed Silurian bank, already described (page 167).

A comparison of the combined thickness of

* *Ibid*, p. 322. In the case of the Burnley section, where the Coal-measures have been partially denuded, the section has been restored on the basis of that of South Lancashire.

coal in the several coal-fields also shows that to a great degree it undergoes a similar loss in thickness along the same tract of country; and as the occurrence of coal-seams in the Millstone grit proves that, from time to time, there were land surfaces approximating to the sea-level, at a period somewhat antecedent to that of the true coal, the subsidence of this region must have amounted to several thousand feet vertical; * the vertical distance between the lowest and highest coal-seam showing approximately the actual amount of subsidence.

In the South of England, on the other hand, the Coal-measures were deposited in greatest force toward the W.S.W., and become attenuated in an E.N.E., direction, as shown by a comparison of the sections in Glamorganshire and the Forest of Dean, which lay in original proximity to the southern slopes of the Silurian bank, which stretched from Salop and Worcestershire into the eastern counties.†

* See observations of Sir C. Lyell on this head. "Students' Manual of Geology," edit. 1871, p. 378.

† See pp. 520, *et seq.*

CHAPTER II.

BRITISH PHYSICAL GEOLOGY.

Origin of Coal-Basins.—The British coal-fields now form a series of basins, some partially concealed by the sea, or by the overspread of newer formations; others visible all round their margins.

The visible coal-basins are: 1. South Wales; 2. Forest of Dean; 3. Burnley; 4. Ayrshire; 5. the Clyde Basin; 6. Mid-Lothian; 7. Tipperary and Kilkenny; 8. Leitrim (Connaught coal-field).

The partly concealed basins are: 1. Somersetshire; 2. the Midland Basin, of which the Denbighshire, Shrewsbury, South Staffordshire, Warwickshire, Leicestershire and North Staffordshire coal-fields form the marginal outcroppings, and of which the northern margin is concealed; 3. the South Lancashire and Cheshire Basin, of which the coal-fields of South Lancashire, Flintshire, and Cheshire form the marginal limits, the southern margin being concealed; 4. the

Yorkshire, Derbyshire, and Notts Basin, of which the eastern margin is concealed; 5. the Northumberland and Durham Basin, of which the eastern and southern margins are concealed; and 6. the Cumberland Basin, of which the eastern and western margins are concealed. In Ireland, the coal-basin of Tyrone is partially concealed. The limits of these several basins are indicated on the general map of the coal-fields which accompanies this volume.

Basins not so formed originally.—It must not be supposed, however, that this basin-shaped arrangement of the upper Carboniferous strata was the original form in which the coal-fields were deposited, like so many lakes filled up with sediment and surrounded by hilly banks and barriers. Such an idea would be altogether erroneous. The basin-shaped structure is in every instance due to terrestrial movements acting along two systems of lines crossing each other transversely, accompanied and followed by denudation.

Original Distribution of Coal-measures.—In order to follow the exceedingly interesting series of changes which have resulted in forming the British coal-basins, we shall first endeavour to ascertain to what extent, and along what limits,

To face page 520.

PLATE XII.

London. Edward Stanford, 55. Charing Cross.

the Coal-measures were originally distributed. The accompanying map (Plate xii.) is intended to illustrate both the areas covered originally by the coal-formation, and those destitute of that covering. From this it will be seen that the coal-area of Britain was distributed into two large tracts, one to the north, the other to the south of a band of country, stretching from North Wales, through Shropshire and Worcestershire, into the eastern counties. The Highlands of Scotland formed the limit to the northward for British Coal-measures, while the Highlands of Donegal, Mayo, and Galway formed the limit of the Irish Coal-measures. Through these great sheets of Carboniferous rocks the Cumberland mountains and a little of the Southern Uplands of Scotland protruded; while in Ireland the mountains of Wicklow and of Slieve Croob were also uncovered; but with these exceptions, we have the most conclusive evidence, that the Coal-measures were continuous over the large tracts occupying the Centre and South of Ireland, the Centre of Scotland, and the North and South of England.*

I have stated at length the evidence upon which this view is supported in the Memoir "On the Triassic and Permian Rocks of the Central Counties of England," Mem. Geol Survey,

Terrestrial Movements at the Close of the Carboniferous Period.—At the close of the Carboniferous period, terrestrial movements took place over the whole of the British Islands and the neighbouring parts of the Continent of Europe, arising from the contraction of the earth's crust, due to the secular cooling thereof. These movements seem to have produced their most powerful effects upon the strata in the South and North of England, and are less discernible in the central part. The forces, however, acting in approximately north and south directions, took the form of lateral pressure, produced flexures in the Carboniferous strata at right angles thereto; in other words, along axes ranging nearly east and west.*

The arches (or anticlinal axes) rising into ridges and traversed by fissures, were subjected to denudation on a large scale, and considerable tracts of Coal-measures were swept away and destroyed. One of these great arches, which it-

p. 109 (1869). Also in my evidence before the Royal Coal-Commission, Report, vol. ii.; and at the meeting of the British Association, Liverpool, Trans. p. 74 (1870).

* In Lancashire the axes ranged along the line of the Pendle Ridge in an E.N.E. direction. In Yorkshire it was nearly E. and W. In the South of England, Belgium, and France, nearly E. and W.

self included several minor folds,* was formed over the tract between the Yorkshire and Lancashire coal-fields on the south, and the Durham coal-field on the north. The denudation which took place over this tract laid bare the Millstone grit and Yoredale rocks, and determined the boundaries of the coal-fields just named.

Another axis, or system of flexures, originated along the southern margin of the Carboniferous Limestone region of Derbyshire, extending westward along the valley of the river Dane, north of Congleton Edge, and, as I have shown on a former occasion, beneath the Triassic plain of Cheshire, emerging on the western side at the southern end of the Flintshire coal-field.† This lower Carboniferous axis forms, in my opinion, the southern border of the Lancashire and Cheshire Coal-basin, as stated above.‡

South of England.—Other east and west flexures were also originated at this period, the

* As shown by Professor Phillips, "Geology of Yorkshire," and by the Author in his paper "On the Relative Ages of the Physical Features and Lines of Elevation of Lancashire and Yorkshire," Quart. Journ. Geol. Soc., vol. xxiv., p. 323.

† See Author's paper on "The Evidences of a Ridge of Lower Carboniferous Rocks beneath the Triassic Formation of the Plain of Cheshire," Journ. Geol. Soc. Lond., vol. xxv., p. 171.

‡ Page 519-20

most important being those of the south-west of England, shown by the longer axis of the South Wales Coal-field, and the uprising of the Carboniferous Limestone of the Mendips. These flexures doubtless extend under the Cretaceous rocks of the south of England, and are continued into the Franco-Belgian trough, and even across the Rhine into Westphalia.* All these leading flexures ranging east and west approximately, accompanied by the denudation of a vast amount of upper Carboniferous material, took place before the Permian strata were deposited; † and partly during it—in fact, during that long lapse of time which intervened between the close of the Carboniferous and the commencement of the Triassic period.

Distribution of Permian Strata.—Over the bent and denuded edges and surfaces of the Carboniferous strata the Permian rocks were distributed; those of central England, within

* As far as I am aware, I was the first to show the pre-Permian age of these E. and W. flexures of the S.W. of England in my paper, of which only an abstract is published in the Trans. Brit. Assoc. Liverpool, p. 75 (1870).

† As there are no Permian strata in the South of England or Wales, it is probable the denudations went on over this area throughout the Permian period.

a basin only a little more extended than that of the Coal-measures themselves; the Permian beds of this tract being separated from those of the north of England by a ridge of lower Carboniferous land stretching from Charnwood Forest in Leicestershire, through Derbyshire, mid-Cheshire (along the concealed axis), into North Wales.* These Permian strata were thus deposited on Lower Carboniferous rocks over some parts of Yorkshire, North Lancashire, and Cumberland; while in South Lancashire, and parts of Yorkshire, Derbyshire, and Notts, they repose on various portions of the Coal-formation.

Terrestrial Movements at the close of the Permian Period.—At the close of the Permian period, a new series of terrestrial movements took place, but *now* along lines ranging approximately north and south, and nearly at right angles to those which preceded them. These disturbances, accompanied by denudation acting chiefly along the arches or anticlinal axes, resulted in the disseverance of the Coal-fields of Lancashire and Cheshire on one side, from

* See my reasons for this view in the paper already quoted, Journ. Geol. Soc., vol. xxv., p. 171, and chap. iii. of the Memoirs "On the Triassic and Permian Rocks of the Central Counties," p. 28.

those of Yorkshire, Derbyshire, and Notts on the other. It was by this process that the Pennine chain, or great central ridge, of the North of England was upheaved, and stripped of its covering of upper Carboniferous beds.* During the same period of disturbance the western limits of the Flintshire and Denbighshire coal-field were determined; also, the north and south axis along which the Durham coal-field is inferred to rise and crop out beneath the sea, and which, in its prolongation southwards, is supposed to form the eastern limits of the Derbyshire coal-basin. To the same period may also be referred the disseverance of the South Wales coal-field from that of the Forest of Dean, and the sharp uprise of the Carboniferous strata along the east of the Somersetshire coal-basin.

Basin-shape of Coal-fields due to the intersection of these two axes.—I have thus shown, briefly here, but more fully on other occasions, that the Carboniferous rocks owe their basin-

* That this great N. and S. upheaval took place before the deposition of the New Red Sandstone, is shown by the fact that the anticlinal fault which is the axis of the system of flexures passes beneath this formation at Leek, in Staffordshire, without in the least affecting it. See Maps of Geol. Survey.

shaped structure to the intersection, nearly at right angles, of these two systems of flexures, viz.—

1. The earlier being pre-Permian, ranging along approximately east and west lines.

2. The latter being pre-Triassic, ranging along approximately north and south lines.

The intersection of these systems has caused numerous complications in the strata, which have been increased by disturbances of later date, while the disseverance of the basins from each other, has been the necessary consequence of the enormous amount of denudation which took place chiefly over the arches or anticlinals.

On the other hand, the existing coal-basins lie in the synclinal troughs which were enclosed within the anticlinal arches.

Distribution of the Secondary, or Mesozoic, Strata.—It will be apparent, from what I have now stated, that the coal-basins received their form before the deposition of the New Red Sandstone, and the Secondary strata which were subsequently spread over the Carboniferous rocks, and served to protect the coal-fields from further denudation during a long lapse of geological time.

The manner in which the Triassic formations

were themselves deposited deserves special observation, and bears directly on the question of the depth at which the Coal-measures may be supposed to lie hidden over considerable tracts of country. This enquiry will form the subject of the next, and concluding, chapter.

CHAPTER III.

DISTRIBUTION OF THE MESOZOIC FORMATIONS.

South-easterly Attenuation of Strata.—Some years since I was led to make a comparison of the thickness of the Liassic and Triassic strata over various parts of England, taken from the accurately-measured sections of the Geological Survey; from which it was shown that they were originally distributed in such manner as to attain their greatest development toward the north-west of England, becoming attenuated toward the south-east.* This south-easterly attenuation of the Mesozoic strata will be apparent upon a comparison of the following sections, founded on actual admeasurements of the Government surveyors:—

		Cheshire and Lancashire, N.W.	Staffordshire, Midland.	Warwickshire, S.E.
New Red Sandstone or Trias.	Keuper series ...	3,450 ft. ...	1,200 ft. ...	600 ft.
	Bunter " ...	2,150 ft. ...	800 ft. ...	absent.
		5,600 ft.	2,000 ft.	600 ft.

* See Author's paper "On the South-Easterly Attenuation of the Lower Secondary Rocks of Engladn," Journ. Geol. Soc., vol. xvi., p. 63. (1860).

Here it will be observed that the attenuation of the Trias is so rapid, as to lead us to infer that, in its prolongation southward and eastward from Warwickshire, it does not extend far below the Chalk of Cambridge or Bedfordshire; although it would appear that the saline waters of St. Clement's Well at Oxford are, as Professor Prestwich infers, derived from the Keuper Marls,* which, it will be observed above, are 600 feet thick near the borders of the Lias in Warwickshire.

In order to extend this comparison of development to the Lias, I shall now give the following comparative sections measured on several occasions at Bredon Cloud,† a hill at the north-west of Gloucestershire, at the Cotteswold Hills near Winchcombe, and in the valley of the Evenlode at Stonesfield in Oxfordshire:‡—

* The water from St. Clement's Well and borehole has been analyzed by Mr. W. F. Donkin, who finds that it contains 493 grains per gallon of sulphates of soda and lime, and 748 of chloride of sodium. Such saline waters can only be derived from strata containing deposits of gypsum and rock-salt such as those of the New Red Marl formation; *Proc. Ashmolean Soc.* 1876.

† Hor. Sections, Geol. Survey, Sheet 60.

‡ "Geol. of Woodstock," Mem. Geol. Survey.

		Bredon Cloud, W.N.W.	Cotteswold Hills.	Stonesfield.	Oxford. S.E.
Lias...	Upper	880 ft.	200 ft.	10 ft.	...200 ft.
	Middle	250 ft.	150 ft.	15 ft.	
	Lower	700 ft.	unknown...	unknown	

The positions of the above localities lie in a relative direction from N.N.W. to S.S.E., nearly parallel to the attenuation of the Triassic strata; and the determination by Professor Prestwich of the existence of the Keuper Marls at a depth of only 420 feet under Oxford, below beds consisting of Oxford clay and oolitic strata, shows that the attenuation of the Liassic beds is continuous at least thus far, the thickness of the three members of the formation being probably under 200 feet. This attenuation is no doubt partly due to the proximity of the shelving shore of palæozoic land which underlies the Thames Valley, and in part, also, to the lessening of sediment in the Liassic sea itself. Upon the same principles we cannot but conclude that all the members of this formation originally overspread the plains of Lancashire and Cheshire in great force.*

The distribution of the Lower Permian strata is somewhat irregular, as they attain a thickness of 1,800 or 2,000 feet in Staffordshire and War-

* Outliers of the Lower Lias occur in Cheshire and Cumberland, the remnants of a once widespread formation.

wickshire. Their development in Lancashire is variable.

Denudation of Mesozoic Strata.—It is therefore evident that the Coal-measures of the central and north-western counties of England and Wales have been at one time buried beneath an enormous accumulation, amounting to several thousand feet, of Lower Mesozoic strata;* but it is still more worthy of observation that this *greatest* vertical development took place over those districts which are occupied by the rich coal-fields of the shires of Derby and York, Lancaster, Flint and Denbigh, Salop and Stafford, subsequently laid bare and rendered accessible by successive denudations. On the other hand, as we have seen, the same post-Carboniferous strata become thinnest in the direction of the eastern counties;—over those districts where we believe the Coal-measures have never been formed, and where, if penetrated, we should only reach Silurian and other rocks of an age anterior to the coal-formation. Thus we see that the various denudations have been more effectual in removing the Secondary strata over those parts of England where they overspread the coal-formation, than in those districts where

* The terms "Mesozoic" and "Secondary" are synonymous.

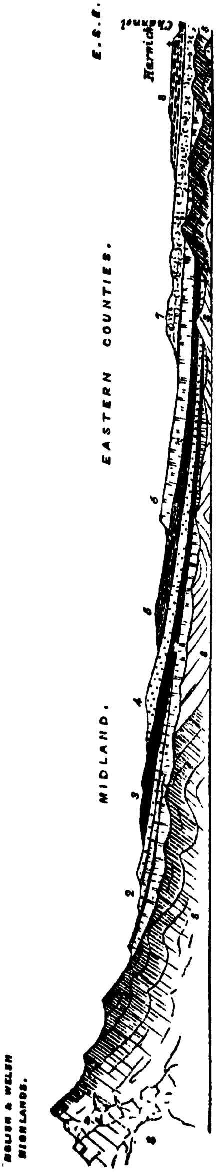


Fig. 24—IDEAL TRANSVERSE SECTION OF ENGLAND.
To illustrate the South-easterly attenuation of the Carboniferous and older Mesozoic Formations, as also the position of the Palæozoic Rocks under the Eastern Counties.

S. Silurian and Cambrian Rocks, forming the foundation for the more recent strata.
2.—Lower Carboniferous Rocks.—3. Coal-measures.—4. Trias and Permian.—5. Lias.—6. Oolite.—7. Cretaceous.—8. Tertiary.

they overlie rocks older than the coal-formation, and therefore destitute of that mineral.

The reader will be assisted in the comprehension of this subject by the following ideal section, which (minor details being omitted) is intended to illustrate the past and present distribution of these strata along a band of country stretching from north-west to south-east across Central England (Fig. 24).

The original foundation upon which rests the Carboniferous system is shown to be the Silurian and Cambrian rocks, as we find to be the case in Staffordshire and Leicestershire. The Coal-

measures are represented by a black band, thickest towards the north-west, becoming thinner and ultimately ending against the older rocks towards the south-east. The overlying formations are also represented, each outcropping in succession towards the north-west, in which direction they become most largely developed, and thinning away towards the south-east. It will be observed that the coal-formation comes to the surface where it is most productive, and that the overlying formations have been most unsparingly swept away where they have originally been deposited in greatest force.

Maximum Denudation towards the North-west.—Now, this enormous denudation is a consequence of the upheaval which the formations have experienced at several periods; and as the strata on the whole dip towards the south-east, the elevatory forces have constantly acted with greatest energy in the direction of Wales, Westmoreland, and the north-western counties, and over the areas of several of the coal-fields, as also along an axis passing along the Pennine Chain; but they have all combined to produce one grand result, namely, the exposure of the Carboniferous rocks towards the north-west of England.

Let us now regard this subject from another point of view. Supposing for a moment that the elevatory forces had acted with the greatest energy and effect along the south-east of England so as to produce a general dip towards the north-west; in other words, that the tilting of the strata had been caused in a direction opposite to the actual dip of the strata;—what, let us inquire, would have been the result?

The answer is obvious; and we can state positively that, to all intents and purposes, England would have been almost as destitute of coal as she would have been had there been no Carboniferous formation. Let the reader glance at the ideal section (p. 533), and then imagine the dip reversed, and the denudation to have taken place *principally* towards the south-eastern side. Two results will at once present themselves. In the first place, the old pre-Carboniferous rocks—those of the Lower Palæozoic age—would occupy the right-hand side of the section, and on the left-hand side the coal-formation would nowhere reach the surface, as it would lie buried beneath an accumulative depth of Secondary rocks: upon it would be piled strata belonging to the Permian, Triassic, Liassic, and Oolitic systems, 6,000 to 8,000 feet

in depth, rendering the coal inaccessible. Even supposing the elevation of the highlands of England and Wales to have occurred for the most part, as was undoubtedly the case, before the Carboniferous period, these mountains would have been enveloped and probably smothered in the embrace of the post-Carboniferous strata; and the highlands of England would have lain along the region now occupied by the Cretaceous and Tertiary rocks. Under these conditions, Britain would have formed but an appendage of the European Continent. She could not, in all probability, have assumed that insular position which, through the favour of an overruling Providence, has rendered her "a shadow from the heat, a refuge from the storm" to the oppressed of Christendom.

I think, then, it must be evident that there is a fortunate relationship between the original disposition of the rocks, and their present distribution; we might even go further and assert that this has been highly advantageous to the commercial and manufacturing prosperity of the country;—a condition of things which involves a long train of moral and social results. England might have become a rich commercial country like Holland, but never a manufacturing one as

she is at the present day except under the physical conditions I have here, but briefly, pointed out. To the teleologist such facts will furnish new arguments; to all reflective minds they cannot fail to afford subjects of interest.

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